To: Sir John Eden, Bt., M.P.,

Minister of State, Ministry of Technology

1. Introduction

Appointment and terms of reference

1. I was appointed by the Paymaster General, the Rt. Hon. Harold Lever, M.P., on 13th March 1970, to undertake an inquiry into the safety of natural gas, with the following terms of reference:

'To inquire into the safety of natural gas as a fuel, and to report'.

2. In requesting me to undertake this Inquiry the Paymaster referred to public concern which had arisen in connection with conversions of domestic appliances to burn natural gas and asked me to give special attention to the intrinsic qualities of natural gas which were relevant to safety in its use as a fuel, particularly in comparison with town gas.

Procedure

3. I have sought evidence:

i. On the extent of public concern as indicated by correspondence to Members of Parliament, the Area Gas Boards, the Ministry of Technology and the Press.

ii. From scientific associations and their individual members, on the physical and chemical characteristics of natural gas.

iii. From members of the medical profession, on toxic hazards related to the use of natural gas.

iv. On the scientific and technical basis of the distribution and use of gas in Great Britain, in so far as it is relevant to safety, in particular:

(*a*) The experimental work carried out by the Gas Council's Research Stations in connection with the safe use of natural gas.

(*b*) The testing and approvals procedures operated by the Gas Industry in connection with gas-burning appliances.

v. On the application of the National Building Regulations and other regulations and codes of practice relating to safety in the use of gas and the installation and use of gas-burning appliances.

4. I have sought the opinions of:

   i. The Trade Unions responsible for the interests of workers in the Gas Industry on a number of matters, including the conversion of domestic appliances to natural gas.

   ii. Manufacturers of gas appliances and conversion contractors, on problems relating specifically to the conversion operation.

5. I have conducted my inquiry by taking written and oral evidence from the persons named in Appendix 11 and I have greatly appreciated the co-operation I have received from them.

6. The inquiry has included visits to:

   i. The Gas Council's Research Establishments at Fulham and Solihull.

   ii. The Ministry of Technology's Gas Standards Branch at Leicester.

   iii. Five of the Area Boards, to discuss conversion problems and observe conversion teams at work adapting gas appliances for use with natural gas.

   iv. The main North Sea gas reception terminal at Bacton, Norfolk.

   v. A major gas off-take station at Warburton, Cheshire.

   vi. A site at which a high-pressure gas main was being laid.

   vii. The Belgian and Netherlands gas authorities at Brussels and The Hague to learn something of their experiences with natural gas.

   viii. A selection of domestic gas consumers who had written to Members of Parliament concerning difficulties which arose following conversion of their appliances to burn natural gas.

7. I am indebted to:

   the Chairmen, members and officers of the Area Gas Boards for their courtesy and frankness in providing me with technical information and details of problems encountered in the course of converting their systems to the use of natural gas ;

   the Chairman, members and officers of the Gas Council for information and reports on various aspects of the inquiry, and for their prompt attention to all queries which have arisen ;

   the Director of the Gas Council's Watson House Research Station and his staff for their co-operation in conducting several experiments which became necessary in the course of my investigation ;

   the Controller of Gas Standards, Ministry of Technology, for information on safety regulations relating to the use of gas ;

Dr. A. E. Martin of the Department of Health and Social Security and Dr. B. Commins of the Medical Research Council's Air Pollution Research Unit for advice and help on the medical aspects of carbon monoxide poisoning;

Mr. O. H. Lawn and Mr. J. H. Garnham Wright of the Ministry of Housing and Local Government for guidance on the Building Regulations;

the Directors of the Fire Research Station (Ministry of Technology and Fire Offices' Committee) and the Ministry of Technology Safety in Mines Research Establishment, for statistical and general information on fires and explosions arising from the use of gas;

the Directors and staff of Electrogaz, SA for the opportunity of visiting their laboratories at Forest and seeing a conversion team at work in Brussels;

Mr. A. De Groot and the Directors of the VEG Gas Institute, The Hague, for much valuable information relating to the use of natural gas in the Netherlands and for permission to use some of this information in my report;

technical staff and workmen of the Area Gas Boards, the conversion contractors and appliance manufacturers for their patience in answering many questions;

many individuals who wrote to me to express their views and suggest lines of investigation and to others who welcomed me into their homes and assisted my inquiry in every way possible.

8. I have been much helped by my colleague, Dr. P. J. King, who, as my assistant in the inquiry, has made a detailed examination of all the technical evidence, has carried out the many calculations required and has been responsible for the preparation of Appendices 3 and 4.

9. I am most grateful to the Secretary to the Inquiry, Dr. L. J. Jolley whose intimate knowledge of the gas industry has been of great value. In addition to most helpful comments on all matters relating to the inquiry, Dr. Jolley has contributed several of the appendices and, with Dr. King, has materially assisted in the preparation of the report. Dr. Jolley's colleagues in the Gas Division of the Ministry of Technology have helped in many ways, and I would particularly thank Mr. E. A. Styles for his valuable assistance at all stages of the inquiry.

2. General considerations

10. Energy is distributed and used in a modern technological community in a variety of forms. The primary forms of energy distributed in this country are solid fuels (mainly coal and coke), liquid fuels such as gasoline, diesel oil and fuel oil, gaseous fuels such as coal gas and other forms of town gas, and electricity. Each of these forms of energy requires special means of distribution to consumers, and each requires special provisions to protect the community which uses them, for by their very nature all forms of energy can give rise to hazardous conditions. If used correctly in well designed and maintained equipment, they can be used with safety; but failure of apparatus, accidental breakage or misuse of equipment can in all cases lead to unsafe conditions and accidents. An indication of the nature, distribution and character of such accidents is given in Appendix 2, and it is against this background that the safe use of natural gas must be considered.

11. Gaseous fuels have been used in this country since the beginning of the 19th century and their use has extended from the early period, when gas was mainly used for street lighting, to a wide variety of industrial, commercial and domestic applications. The present organization of the Gas Industry in Great Britain is described in Appendix 1. Prior to 1960 the bulk of manufactured gas in this country was made by the carbonization of coal, augmented at certain times of year in certain areas by special gases such as carburetted water gas, and, in more recent times, by gases made from petroleum products. Such gas was rightly regarded as a convenient and satisfactory fuel, particularly in domestic appliances. There were, however, certain hazards associated with the use of coal gas of which the public were well aware and against which they were prepared to take the necessary precautions to ensure the safe use of this convenient fuel. In particular, coal gas contained carbon monoxide, a very toxic gas, and occasional leaks of coal gas led to mishaps and fatalities. As the use of gas expanded, the number of such fatalities increased and both the Gas Industry and the Government were rightly concerned with this.* The development in 1960 and immediately there-

* *c.f. inter alia:*

i. Report of the Departmental Committee appointed to enquire into the manufacture and use of water gas and other gases containing a large proportion of carbonic oxide. HMSO, London, 1899, Parliamentary Paper C. 9164.

ii. Report to the Board of Trade by the Fuel Research Board on Gas Standards. HMSO, London, 1919, Parliamentary Paper Cmd. 108.

iii. Report to the Board of Trade of the Departmental Committee on Carbon Monoxide. HMSO, London, 1921, Parliamentary Paper Cmd. 1422.

iv. 'The Detoxification of Town Gas'. (An internal report by Chief Scientist's Division, Ministry of Power, 1961, which was made available to this inquiry.)

after of new processes for the manufacture of gas from petroleum naphtha reduced the cost of gas manufacture and at the same time reduced the content of carbon monoxide in the gas. The hoped-for reduction in accidents from gas poisoning followed almost immediately, the number of reported accidental deaths from this cause being reduced from 1193 in 1963 to 369 in 1968 and 316 in 1969 (cf. Appendix 2). The advent of natural gas in sufficient quantities to ensure the requirements of Great Britain for at least the next 25 years presented the gas industry with the possibility of distributing a gaseous fuel which could be completely non-toxic. This possibility has, in fact, been realized in the Netherlands where conversion to natural gas was completed in 1967. This conversion has been accompanied by a dramatic reduction in the number of fatalities from gas poisoning, and in 1967 not one single fatality from gas poisoning occurred.

12. A study of the medical literature and evidence submitted to the inquiry by Dr. A. E. Martin of the Department of Health and Social Security confirms that methane itself is completely non-toxic and that natural gas, such as is distributed in this country, i.e. a gas consisting essentially of methane with very minor proportions of other gases, should also be non-toxic.* The inquiry is therefore satisfied that the use of natural gas in this country will remove the major hazard associated with town gas and incidents of gas poisoning should no longer occur. It must be noted, however, that an atmosphere consisting entirely of methane cannot be breathed safely by human beings because of the lack of oxygen, and can lead to death from asphyxiation. Such conditions are unlikely to occur on consumer premises or as a result of leaks or breakages in the distribution systems. They could, however, occur within, for instance, gas holders used to store natural gas, and the safety regulations which now apply to the 'gas free' testing of tanks etc. to ensure the safety of workers subsequently entering the tanks must continue to apply.

13. Town gas, however, has other associated hazards and these may be classified as those due to fire and explosion which occur when gas escapes and is ignited, and as that due to carbon monoxide poisoning arising from the incomplete combustion of the fuel in unventilated or inadequately

* 'Methane and ethane are pharmacologically 'inert'; and belong to a group of gases called 'simple asphyxiants'. These gases can be tolerated in high concentrations in inspired air without producing systemic effects. If the concentration is high enough to dilute or exclude the oxygen normally present in the air, effects produced will be due to oxygen deprivation or asphyxia'.
'Methane has no appreciable physiological action except when it lowers the partial pressure of oxygen in the air enough to cause systemic effects due to oxygen deprivation.' H. W. Gerarde, in 'Industrial Hygiene and Toxicology', 1963 (2nd Ed.), p. 1196.

flued rooms or premises. These hazards are present with natural gas and evidence has therefore been sought to ascertain whether the use of natural gas introduces a greater hazard than existed with the use of town gas. The terms of reference of the inquiry have therefore been interpreted as requiring a comparison of the safety of natural gas as a fuel with the safety of town gas as a fuel. This has involved a detailed study of the chemical and physical properties of town gas and natural gas, of the character of the equipment by which gas is transmitted, distributed and metered into the consumers' premises, of the suitability of the appliances in which it is used, and of the precautions which have been taken to ensure the safe use of the fuel. In the course of the inquiry evidence has been presented which relates to the safe use of any gaseous fuel and whilst the facts elicited are well known within the gas industry, they do not appear to be fully appreciated by others professionally concerned or by the general public. It has been thought desirable to include such matters in this report, although they may be considered to be outside the original terms of reference, in the hope that the findings may be of use to authorities considering such matters as the Building Regulations, future legislation, British Standard Codes of Practice and other matters related to this subject.

14. Early evidence presented by several witnesses indicated that public concern had arisen more from incidents related to the conversion operation than from the character of natural gas itself. Although the majority of letters received by Members of Parliament and by the inquiry were essentially accounts of inconvenience rather than danger, the suggestion was accepted that such incidents as were reported might be an indication of a potentially hazardous situation. Accordingly a detailed examination of the conversion operation has been made.

15. Much of the information collected and analysed in this report is of a technical nature. Wherever possible such information is presented as appendices in order to reduce the length of the report and at the same time to enable the established facts and conclusions drawn therefrom to be presented clearly and in a logical order.

3. Natural gas and town gas

16. An account of the composition and combustion characteristics of all the gases relevant to this inquiry is given in Appendix 3. Table 4 of Appendix 3 presents a comparison of the more important characteristics of a typical town gas such as is currently supplied in this country, and of the natural gas from the North Sea gas fields now being distributed in many areas. This table is reproduced at this point in the report to facilitate the subsequent discussion.

Characteristics of G4 town gas and natural gas

	Town gas (G4)	Natural gas	Ratio NG/TG
Calorific value (Btu/cuft) . . .	500	1020	2·0
Specific gravity	0·475	0·584	1·2
Wobbe number $\left(\frac{\text{calorific value}}{\sqrt{\text{specific gravity}}}\right)$	730	1335	1·8
Maximum burning velocity (cm/s) .	80 (approx.)	35	0·4
Limits of inflammability (per cent.) .	4–40	5–15	—
Gas in mixture at 50 per cent. primary aeration (per cent.)	31·7	17·3	—
Air required for complete combustion (cuft/1000 Btu)	8·8	9·4	1·07
Carbon monoxide content (per cent.) .	3–20	0	—
Sulphur content (lb/10^6 cuft) . .	0·5–40	0·2–0·8	—
Volume of flue gas (cuft/1000 Btu) .	10·2	10·4	1·02
Volume of CO_2 (cuft/1000 Btu) . .	1·01	1·00	0·99
Burner pressure (in w.g.) . . .	2·5	8·0	3·2

17. The values given in the above table for physical and chemical properties of the gases (calorific value, specific gravity, Wobbe number, burning velocity, limits of inflammability, carbon monoxide content and sulphur content) have been supplied by the Gas Council or taken from the current literature. The figures for volume of air required per 1000 Btu, volume of gas in a mixture at 50 per cent. aeration, volume of flue gases produced per 1000 Btu and volume of carbon dioxide produced per 1000 Btu have been calculated from the chemical analyses of the gases.

18. The combustion characteristics of a gas determine the type of burner required for satisfactory use in a gas burning appliance and also determine the combustion space and flue dimensions needed. A discussion of these factors is given in Appendix 3 and will be referred to again in the

appropriate sections of this report. It is necessary at this point, however, to draw attention to certain differences between the two types of gas, town gas and natural gas, which have made the conversion operation necessary.

19. Natural gas has approximately twice the *calorific value* of town gas. Thus, to supply a given quantity of heat the volume of natural gas required is approximately half that of town gas. This is more clearly illustrated by the *Wobbe number*, which is the ratio of the calorific value to the square root of the specific gravity (air=1) and is a measure of the thermal value of the gas delivered per unit time from a given orifice at a given pressure differential. The Wobbe number of natural gas is nearly twice that of town gas and therefore to deliver a given rate of heat supply a burner must be provided with a smaller diameter jet for natural gas than town gas. Thus, in order to use natural gas in appliances designed to burn town gas it is necessary to replace the existing burners by new burners of appropriate design for the particular appliance to give the correct heat output and to maintain stable flames. Moreover, to enable the new burners to function satisfactorily it is also necessary to supply natural gas at the burner nozzle at a somewhat higher pressure (8 inch water gauge) than had previously been the case.

20. Thus, the use of natural gas throughout the whole of the gas industry required:

firstly, a new transmission system to transport the natural gas from the coastal terminals at which it is received to the offtake stations supplying the area Gas Boards ;

secondly, some modifications to the distribution systems within the area boards to supply the gas at the slightly higher pressures required at the consumers' premises, and

thirdly, the conversion of all burners in use in over 6000 different types of appliances in the 13 000 000 or so domestic premises using gaseous fuel.

21. The economic considerations on which the decision to replace town gas by natural gas was based, the scientific and engineering studies which influenced the choice of transmission, distribution and control systems to be employed, and the organization and conduct of the whole conversion operation are matters beyond the scope of this report. They have been examined, however, because a full understanding of the problem is necesary

in order to ascertain whether all necessary and reasonable precautions have been taken to ensure the safe use of natural gas.

22. It has already been stated that the non-toxic character of natural gas removes the hazard of gas poisoning and thus creates a much safer fuel system. It remains now to examine the hazards of explosion and fire and the problems of incomplete combustion.

4. Hazards of explosion and fire

23. Fire occurs when gas escapes from its containing system, mixes with air and is ignited from some source. Explosion results when the speed of flame travelling through the gas/air mixture exceeds certain limits and particularly when the gas/air mixture is confined. The gas may escape as the result of leakages in transmission and distribution lines, failure of joints to remain gastight, leakage through pipe walls as the result of corrosion, or from ill-fitting or maladjusted connections. It may also escape as the result of careless or accidental misuse of an appliance or from the failure or malfunctioning of the appliance.

Hazards from high pressure bulk transmission system

24. An account of the main features of the high pressure (550–1,000 p.s.i.) bulk transmission system is given in Appendix 4(a). The pipelines are manufactured, assembled and laid to very exacting specifications and codes of practice established by the Institution of Gas Engineers. These standards, covering steel quality, welding techniques and testing, protection from corrosion, resistance to accidental damage (fracture toughness) and additional safeguards at points of increased risk such as road, railway and river crossings, are at least as exacting as those in use elsewhere in the world. An additional safeguard, adopted in 1968, is to subject all new pipelines to a hydraulic pressure test up to the specified minimum yield point of the steel for 24 hours. This practice has also been adopted by some American pipeline companies and in a typical case one such company has had no service failures over several thousand miles of pipeline over the period of years since testing to yield has been practised.

25. The route is selected to avoid built-up areas and areas scheduled for future development. The agreement with landowners allows for a permanent easement of 20 ft in which no building or construction work in permitted and additionally 10 ft support strips on either side in which work can only be carried out with permission of the Gas Council. Isolating valves are provided at regular intervals, the above ground installations are contained with high security fences and the vulnerable equipment and instrumentation securely housed. Every precaution has been taken to ensure maximum safe operation of the system.

26. Any risks associated with the high pressure transmission of natural gas can be regarded as superseding the risks associated with the manufacture of town gas in coal carbonization plants or in modern catalytic

oil and naphtha reformers, which involve the transportation to the manufacturing unit by rail or road of large quantities of liquid petroleum products and the subsequent storage of the gas produced in centrally placed gas storage equipment such as the gas holder. The safety record of such installations is excellent. There is no reason to believe that any greater risk exists with the high pressure transmission system. Indeed, the modern technology associated with pipeline construction, maintenance and operation is well established and accepted as safe practice.

Hazards from area distribution systems

27. Medium and low-pressure (see Appendix 4(b)) feeder and street mains are occasionally of welded steel construction but are more often built up of sections of cast-iron pipe connected by socketed joints. The traditional type of joint in the older cast-iron mains, of which there are many thousands of miles throughout the country, is the open-socketed type in which the sealing material is hemp yarn held in position by lead. The transition to dry manufactured gas and natural gas has caused frequent leakages from these joints as a result of the drying out of the hemp packing, and all Area Boards have put into operation systematic programmes of leak surveys throughout their systems, using the very sensitive flame-ionization method of detection. Leaking joints are clamped and a number of methods of internal sealing (oil fogging, glycol spraying, application of plastic coatings internally, etc.) are being used. A special method of clamping the more modern hook-bolt joints which rely on a rubber gasket for tightness has also been introduced, and in new mains special types of bolted joint which remain tight with dry gas are in use. As a result, the number of leaks per mile of main has dropped significantly in the last few years.

28. Leakage from the older types of gas main has been a familiar problem for many years and the Gas Boards are well aware of both the danger from leaks and the cost to themselves of any substantial losses of gas. The use of higher pressures, drier gas and latterly natural gas in the district systems has caused the Gas Boards to undertake intensive programmes of clamping, sealing and—where necessary—renewal. Moreover, planning the conversion of distribution systems to natural gas involves a detailed survey of the pipework and a sophisticated network analysis of the flow of gas in each sector before conversion can be put in hand. In some cases the survey has revealed the existence of old mains which were not in the Board's records. The overall effect of all this survey, inspection and sealing work has undoubtedly been to improve the

safety of existing gas distribution systems, even under the heavier duty to which they are being subjected by increasing gas loads and the use of natural gas. The total length of all gas mains in the country is so vast, however (of the order of 120 000 miles of main and several millions of joints), that many years will be needed for the elimination of all leaks.

29. The transmission and distribution of gas in bulk on a national scale through a complex network of pipelines operating over a wide range of pressures has necessitated the installation of a number of reception and despatching stations equipped with pressure reducing and metering equipment. This inquiry has included inspection of a number of these and the high technical standards observed in their design and equipment are impressive. The level of built-in safety precautions is high.

Hazards from service pipes

30. Gas is supplied from the street mains to consumers' premises through small diameter (about 1 in.) pipes, usually of mild steel and buried in the soil. Modern practice includes effective means of preventing corrosion and consequent leakage by the use of wrapped or cathodically protected pipe, but old service pipes laid before these practices were adopted are sometimes corroded and are a frequent source of leaks. The leakage surveys which all Boards now put in hand prior to conversion undoubtedly improve the overall safety of the system by revealing defective service pipes, which are renewed before conversion to natural gas is due.

Hazards from internal pipework

31. Internal installation pipework in premises (carcassing) is mainly in mild steel with screwed taper-thread joints, but copper, brass and lead pipe-work is used to a certain extent. In all modern installations the materials and joints are to British Standard specifications devised specifically for such pipework, but there are undoubtedly many installations in old property which are sub-standard or in poor (corroded, leaky or partially blocked) condition. It is standard practice for Gas Boards as part of their preparations for conversion of each sector of their supply systems to natural gas, to subject all installation pipework to a pressure test at above the set pressure of the meter governor referred to below. Any leaks found must be repaired and defective parts of the pipework renewed or blanked off before the Board undertakes conversion of the

premises. Thus it can be expected that the customer's premises are left in a safer condition after conversion than before.

Pressure control at consumer premises

32. Part of the conversion procedure is to install a governor (pressure controller) between the service pipe and the customer's meter. This provides an additional factor of safety, since it ensures that should gas be accidentally admitted to the street mains at an excessive pressure, the risk of damage to the meter or internal installations is minimized (see Appendix 4(b)).

Hazards from appliances

33. Leaks in connections to gas appliances and in the appliance itself can arise from faulty materials or workmanship, in both town gas and natural gas systems. Escapes of unburnt gas can also occur through failure of burners to ignite, as a result of instability or incorrect placing of pilot lights, careless operation of apparatus or failure to relight a pilot flame after the gas has been turned off at the main supply point and turned on again. Statistics on the frequency of such accidental escapes of gas are limited by the relatively short period which has elapsed since conversion, but Appendix 5 gives comparative figures from five Area Boards showing the number of gas escapes reported. Each Board was asked to choose two areas of roughly similar size and character, one being supplied with town gas, the other area supplied with natural gas for at least one year. All reports of gas leakage of whatever nature occurring within the same period of seven days are included in the survey. The figures show no significant overall difference in the reported occurrence of leaks between the two types of gas, but indicate minor points of difference which appear to merit further investigation by the gas industry.

Comparison of explosive character of gas/air mixtures

34. On theoretical grounds it may be argued that because natural gas has a higher ignition temperature and narrower limits of inflammability, explosions should be less likely to occur than with town gas. The energy released by the explosion of a stoichiometric mixture of gas and air is the same for both gases, but some evidence has suggested that due to the higher flame speed of hydrogen in the gas/air mixture the 'impact' of a town gas explosion in a partially vented room or oven might be

879673 A 5

greater than a similar explosion of natural gas/air mixtures (see Appendix 3). In considering the safe use of natural gas the practical difference between the two gases in respect of ease of explosion and explosive violence does not appear to be significant and it is therefore concluded that the damage which an explosion might create is virtually the same with both types of gas.

35. There is support for this conclusion in the figures supplied to the inquiry by the Fire Research Station (Appendix 6). In town gas areas, the number of explosions in dwellings per million therms of gas consumed has remained nearly constant over several years. In natural gas areas the number per million therms, although higher in 1969, is still too small to be regarded as evidence of any greater hazard. This conclusion is supported by the statistics shown in Appendix 5 for the incidence of leaks. It is also evident from the character of the fires reported that the extent of damage done by natural gas explosions does not differ greatly from the damage done by town gas explosions. Experience in the Netherlands confirms this conclusion; statistics of incidents of fire and explosion over the past ten years show that despite the considerable increase in gas consumption following conversion the number of such incidents has remained fairly constant.

36. This inquiry therefore concludes that the explosion and fire hazard associated with natural gas is similar to the hazard associated with town gas and that as a result of the conversion operation the systems by which gas is distributed, the premises in which gas is consumed and the appliances in which gas is burnt should be safer after the conversion operation has been completed than before.

5. Hazards of incomplete combustion

Carbon monoxide asphyxia from incomplete combustion

37. Public attention has been drawn to the hazards existing when gas is burnt in an unflued appliance or one with a blocked flue in an unventilated room. This is not a new problem but has existed with all forms of carbon-containing fuels whenever conditions give rise to incomplete combustion. The following quotation from one of the standard works on carbon monoxide asphyxia is as true today as when it was written in 1938:

> 'When any carbon-containing fuel, such as coal, oil, coke, wood, manufactured gas, or natural gas, is burned in the absence of sufficient oxygen, or whenever, for any reason, combustion is incomplete, carbon monoxide will be formed. This means that in buildings where a furnace flue is blocked or where the combustion chamber of a furnace allows the escape of products of combustion into the circulating air space, in rooms heated by badly ventilated coal or charcoal stoves, in houses where charcoal or coal-burning salamanders are being used for drying or warming during building operations, in the presence of appliances burning manufactured or natural gas and so badly adjusted or constructed as to permit incomplete combustion, and finally, in the smoke from burning buildings, where the fire is, to a degree, smothered—in all of these situations we will inevitably encounter carbon monoxide.' ('Carbon Monoxide Asphyxia', C. K. Drinker, p. 97, Oxford University Press, 1938.)

38. The attention of the inquiry was drawn to this aspect of the safety of natural gas by the statements of several Members of Parliament, based upon letters from constituents and on articles in the Press. Statements made in many Press reports that natural gas burns twice as much oxygen as town gas were based on the misconception that because natural gas requires twice as much oxygen *as an equal volume* of town gas for complete combustion, the same relative consumptions of oxygen would occur in a gas burning appliance. This of course is not true. The calorific value of natural gas is twice that of town gas and the gas burning appliance is adjusted to consume just sufficient gas to produce a given quantity of heat. Since, after conversion, the appliance is operated to give the same heat release with natural gas as was obtained with town gas, the oxygen used is only marginally greater (about 7 per cent.) than before (cf. tables following Appendix 3).

39. Nevertheless it became evident early in the inquiry that a detailed examination of this problem, and the associated problems of design of

appliance, conversion techniques, supply of combustion air and room ventilation was desirable. The factors which have been investigated can best be understood by an examinaton of the combustion of a gas in a free flame, burning in a non-ventilated space, i.e. in a space in which the products of combustion of the gas will accumulate and to which no fresh supply of combustion air is available. Much experimental evidence exists in the scientific literature to substantiate the following facts.

40. The flame is the reaction zone in which the constituents of the gas, methane, hydrogen, carbon monoxide (in the case of town gas) and methane (in the case of natural gas) react with oxygen from the air, and requires that air be available in the form of primary air if the flame is premixed, and secondary air around the flame both for a premixed (bunsen type) flame or a non-aerated flame. The chemical reactions which take place when combustion is complete result in the formation of carbon dioxide and water vapour.

41. In a completely sealed room the oxygen in the air is gradually consumed, and the amounts of carbon dioxide and water vapour in the air gradually increase. This effect is called vitiation. At some point in time, usually measured by the amount of carbon dioxide in the atmosphere, the rate at which oxygen can be supplied to the reaction zone begins to diminish and the flame begins to lengthen, establishing a larger area for oxygen to diffuse into the reaction zone to compensate for the reduced diffusion effect produced by the fall in oxygen concentration in the atmosphere. At this point the amount of carbon monoxide present inside the flame may increase, but the products of combustion still consist entirely of carbon dioxide and water vapour. As the process continues, however, the flame becomes unstable. In the case of natural gas this instability occurs at a lower percentage of carbon dioxide in the air (about 1·5 per cent.) than with town gas (about 2·0 per cent.). If the experiment is continued the flame will ultimately 'lift off' the burner port, and in the case of a single flame this again occurs earlier with natural gas than with town gas. At this point, or immediately prior to it, carbon monoxide appears in the products of combustion and can be measured in the surrounding atmosphere. Although the town gas flame persists—although much lengthened—up to higher concentrations of carbon dioxide in the atmosphere, it also begins to produce carbon monoxide in much the same way, and this can also be detected in the surrounding air. Carbon monoxide appears in both cases as the result of incomplete combustion.

42. The evidence available when this inquiry was commenced indicated that the onset of flame instability occurred at an earlier stage in the

vitiation process with natural gas than with town gas. There was, however, no experimental evidence which compared the times which would elapse before carbon monoxide appeared in the products of combustion from appliances burning the two gases under otherwise similar conditions. Accordingly the Gas Council was requested to conduct comparative experiments in which an appliance fitted with a multi-jet aerated burner was operated in a sealed room at a specified heat output. The appliance was supplied with town gas for the duration of the first experiment and with natural gas for the second. In each case the time taken for the atmosphere in the room to reach unsafe or lethal concentrations of carbon monoxide was recorded. These experiments broadly confirmed calculations made during the course of the inquiry that the time required to produce dangerous conditons in the room would be only marginally less for natural gas than town gas.

43. Consideration was then given to the conditions which might lead to dangerous atmospheres in a room in which a gas burning appliance was used, to analyse the evidence to ascertain if any condition was likely to give greater hazard with natural gas than with conventional town gas. The conditions which contribute in a major way are:

i. blocked or inadequate flue
ii. absence of ventilation in room
iii. flame impingement on heat exchanger
iv. flame impingement on flame
v. soot or deposit on heat exchanger
vi. condition of the appliance

Flue

44. The primary cause of vitiation in a room is the lack of an adequate flue. Absence of flue or a blocked flue leads to products of combustion entering the room. Badly designed flues—e.g. with excessive horizontal traverse—or badly positioned outlets may, under adverse wind conditions, lead to pressure differentials which cause the products of combustion to spill out from the draught diverter into the room. In all such cases the rate at which carbon monoxide concentrations will increase in the room is a function of the rate of air change in the room, the size, i.e. the thermal input of the appliance and, to a lesser extent, the condition of the appliance. Since experiments indicated that in the absence of a flue and with no air change the build up of carbon monoxide in the atmosphere

was much the same for each gas, evidence was sought as to the effect of other factors in relation to type of gas.

Absence of ventilation.

45. The National Building Regulations and the British Standard Codes of Practice (Appendix 8) specify minimum ventilation conditions for rooms in relation to size and use, and require that combustion appliances shall have adequate access of air. At present, however, there is no regulation which ensures that adequate combustion air is necessarily available at the point of combustion whenever an appliance is in use. Even where due attention has been paid in the design of a building to the provision of ventilation, it is usually easy for occupants to seal up ventilators and in other ways to interfere with the access of air to rooms, in the interest of their personal standards of comfort but to the detriment of the safe operation of fuel-using appliances. Present-day standards of comfort incline householders to the provision of fitted carpets, draught excluders and double glazing as additional amenities to living rooms and even to bathrooms, often—and quite understandably—in disregard of the effect these must have on 'adventitious' ventilation and the hourly number of air changes which are essential to the safe operation of fuel-burning appliances in these rooms. If no positive supply of combustion air from outside is provided in such cases, vitiation of the air of the room will set in even if there is a flue—because of course a flue cannot function unless there are means of access to the appliance of a volume of fresh air equal to the volume of waste gases discharged through the flue. The products of combustion will then remain in the room and, as has been shown, will ultimately result in the formation of carbon monoxide irrespective of the type of gas used.

Flame impingement on heat exchangers

46. If the air for combustion is depleted in oxygen, flames of either town gas or natural gas lengthen and ultimately impinge on the heat-exchange surfaces in such appliances as central heating boilers, warm-air units and instantaneous water heaters. The physical and chemical effects of flame impingement are discussed in Appendix 3, in which it is shown that there is no evidence to suggest that when it occurs the amounts of carbon monoxide produced in the waste gases are substantially different for different fuel gases. Flame impingement may occur earlier in the case of natural gas but this does not appear to lead to material differences in the time required to build up toxic conditions in a room.

Flame impingement on flame

47. If multi-jet burners are in bad condition (cracked, misaligned or partially blocked or obstructed so that the flames are distorted) or if, for example, a pilot flame is badly placed, some flames may impinge on each other. These flames are thus starved of secondary air, and combustion in them is likely to be incomplete. Moreover they will be disproportionately affected and lengthened by any vitiation of the air, and more likely to impinge on heat exchanger surfaces, etc.

Flame impingement on soot or other deposits in a heat exchanger

48. Sooting of heat exchanger surfaces appears to result from restriction of the primary air supply to the burner by accumulations of dust or fibre (' linting '), from misalignment of the flames resulting in flame-on-flame impingement or from partial blockage of the burner ports by corrosion deposits, etc. When the exchanger surface is sooted, or covered with other deposits arising from corrosion or other sources, the volume available to the flame for further combustion is reduced. It is known that formation of carbon monoxide is favoured by such conditions, although the precise mechanism of this is not certain. Linting can occur with aerated flames but not with the non-aerated flames which were commonly used with town gas ; hence it is possible for it to become a problem with some appliances when they are converted to use natural gas. Since flame-lengthening also occurs somewhat more readily with natural gas than with town gas, the possibility exists that production of carbon monoxide may occur more readily with natural gas burning in a maladjusted or faulty appliance than with town gas. No direct evidence of this has been presented to this inquiry, but a detailed study of the sequence of events which can occur in appliances in which the supply of primary air is limited by over-gassing or linting points in this direction. Where in addition there is faulty ventilation (lack of combustion air) and above all where the flue is faulty or inoperative, the result will be a rapid build-up of carbon monoxide in the room. Similar effects can be expected with natural gas and town gas, but in the absence of direct experimental evidence it would be wise to assume that the danger of carbon monoxide poisoning arising from a combination of faulty appliance, faulty flue and poor ventilation is marginally greater with natural gas than with town gas.

49. It would seem from the evidence available that this difference is so small as to have no significance in a small room and that with unflued appliances such as water heaters in unventilated bathrooms the onset of

toxic conditions is as rapid with town gas as with natural gas. There is a possibility that the presence of steam in the combustion air not only increases the degree of vitiation but may also contribute in some way to the earlier production of carbon monoxide. One particular type of high-duty water heater has had to be modified by moving the hot water spout away from the air intake to enable it to function satisfactorily with the Dutch natural gas, which contains 14 per cent. of nitrogen. In passing it may be noted that the Dutch gas has even lower flame stability than the natural gas used in the United Kingdom.

Condition of appliances

50. Some references have already been made in this report to the effects of certain faults in appliances. Faulty alignment of burners, partial blocking of burner ports, overgassing, linting and fouling of heat exchanger surfaces can all lead to unsatisfactory combustion. Although all appliances and conversion sets supplied and installed by the Gas Boards and their approved installers and conversion teams are required to satisfy the high standards laid down by the Gas Council's approval procedures, there is no doubt that a certain number of sub-standard appliances and installations still survive—even after conversion—and that occasional errors are made by conversion operatives and fail to be detected in subsequent routine inspections. With the exception of linting, most of the faults which arise are equally possible with town gas and natural gas—the problem of faulty conversion being essentially a matter of defects created in appliances in the course of conversion.

51. Two particular factors, however, appear to merit closer attention by the gas industry than has hitherto been paid to them. Firstly, the gradual deterioration of electrical fittings in such appliances as warm-air heaters. The consumer still tends to regard gas appliances in general as simple robust fixtures which require little maintenance, whereas nowadays many systems have sophisticated control devices which are comparatively delicate pieces of equipment. It often happens that manufacturers have been concerned to fit these into the minimum of space in the interests of overall compactness and they are awkwardly placed and subjected to adverse conditions of temperature or mechanical stress. Secondly, with some of these sophisticated appliances it appears that attempts to provide parity of performance after conversion of an appliance designed to use town gas have led to some sacrifice of such desirable features as ample space for combustion and safeguards against flame impingement and overheating of electrical insulation.

52. Throughout the foregoing discussion on vitiation and carbon monoxide poisoning from incomplete combustion emphasis has been placed upon heavy duty appliances such as instantaneous hot water heaters in bathrooms, central heating boilers and, to a lesser extent, on warm-air units. To a large extent the problem with instantaneous hot water heaters can be solved by the installation of room sealed appliances, and these are increasingly used in place of the older types. The problem of vitiation arising from the use of cookers, hot plates and gas grills in a kitchen is less serious. Usually the apparatus is in use during the daytime with an active person in the kitchen. The first effect of vitiation is an increase in the carbon dioxide content of the air in the room and a rise in temperature and humidity. Long before this reaches dangerous conditions, i.e. those at which carbon monoxide begins to appear, the atmosphere of the kitchen becomes unbearable and the desire for fresh air will lead to almost automatic opening of the kitchen windows. The warm moist atmosphere which would lead to the opening of a window in a kitchen, however, is the very condition which gives rise to danger to a person sleeping in a bedroom or drowsing in a hot bath. Carbon dioxide induces 'hyperventilation' (deep breathing) and if this continues unchecked by the desire of the active person for fresh air, then subsequent inhalation of carbon monoxide will lead to serious poisoning with fatal consequences.

53. Figures supplied by the Gas Council, and a detailed survey of a large number of press reports provided by one Member of Parliament, do not indicate any increase in the number of incidents of carbon monoxide poisoning by incomplete combustion in those areas converted to natural gas over similar incidents in areas using town gas. Some members of the medical profession have made comments which appear to have been based on the misconception already referred to (see paragraph 38) concerning the amount of air used in the combustion of natural gas. One pathologist expressed misgivings on the safety of natural gas, based on the fact that during the eight years preceding 1968, out of 1506 post mortem examinations three were accidental deaths caused by carbon monoxide poisoning due to incomplete combustion of town gas, while between 1968 and June 1970, out of 327 post mortem examinations two were accidental deaths from carbon monoxide poisoning caused by incomplete combustion of natural gas. The two cases arising from the use of natural gas have been carefully examined. One arose from a faultily flued appliance in a badly ventilated bathroom, the other from a non-flued portable gas fire burning in an almost hermetically sealed room. Whilst it is recognized that it is incumbent on Medical Officers, Home Office Pathologists and medical practitioners to draw public attention to any dangerous conditions they

may encounter in the course of their duties, there is no doubt that public safety would be better protected if attention were drawn to the real cause of carbon monoxide poisoning, i.e. faulty ventilation and inadequate flues, rather than to the nature of the fuel.

54. In all reports of incidents examined the inquiry evidence was available to show that the cause of incomplete combustion was a combination of the following circumstances:

i. inadequate, blocked or faulty flue, or no flue

ii. lack of adequate ventilation and combustion air

iii. maladjusted or faulty appliance

iv. prolonged use of unflued water heaters in unventilated small room (e.g. a bathroom).

Similar evidence was made available to the enquiry by the Netherlands Gas Institute, in which the number of incidents involving carbon monoxide poisoning which occurred in 1968 have been analysed in great detail. In every case a combination of factors was established. With unflued instantaneous hot water heaters the major factor was continued use over a long period (1 to 1½ hours) in a badly ventilated room. With flued appliances the major factors were blocked or inadequate flues, inadequate ventilation, blocked burner ports due to dirt or corrosion products and faults in, or malfunctioning of, the appliance. In almost all cases a combination of at least two but more usually three of these factors was involved. Nevertheless an analysis of the figures covering the period 1960 to 1969 did not indicate any significant increase in incidents (about 25 per cent. of which resulted in fatalities) as a result of the conversion to natural gas, despite the great increase in gas consumption following the conversion. It is understood that these figures will be reported to international gas organizations in due course when the period of total natural gas usage has been extended sufficiently to justify statistical analyses.

55. In concluding this section of the report it must be again emphasized that none of the evidence presented to this inquiry supports the view that the dangers of carbon monoxide poisoning from incomplete combustion of natural gas are any greater than similar dangers using town gas or any other carbon-containing fuel. However, the conditions of faulty ventilation which various Area Boards have uncovered during the conversion operation and instances of a similar nature which coroners' reports have described lead to the inescapable conclusion that Building Regulations and British Standard Codes of Practice have been ignored in many

instances. Even where the original installation of the appliance was in accordance with these Codes, subsequent happenings such as the blockage of flues by birds' nests or the sealing of air ducts by the occupant of the premises suggest widespread ignorance on the part of consumers of the dangers inherent in combustion appliances in unventilated rooms or with faulty or blocked flues. The attention of all consumers should be drawn to these dangers by simple pictorial information, for in several instances the printed warnings on appliances have been ineffective where the consumer is unable to read or, as is the case with some immigrant families, is unfamiliar with the English language. It is perhaps relevant to quote again from American literature, and the following abstract from a publication of the Metropolitan Insurance Company (Dublin and Lotka 1937) is particularly apt:

56. 'Vigorous and widespread educational campaigns are called for to combat the dangers of gas poisoning, particularly in the home. All gas tubing and appliances should be inspected by a competent person. A warning should be given against using gas heaters without flues. Furnaces and chimneys should be cleaned and inspected each fall. Operators of automobiles should be repeatedly cautioned, especially when cold weather sets in, against the danger of running engines while garage doors are closed. It is not generally known that the exhaust fumes of a single car render the atmosphere of a small ill-ventilated garage deadly within five minutes. Wide publicity should also be given to the fact that carbon monoxide usually gives no warning and that the first effect is often a muscular weakness which renders the victim helpless. Further, information should be broadcast that in all types of acute gas poisoning, the manual prone pressure method of resuscitation, such as is used in drowning, should be applied immediately. Many lives would be saved in the United States each year if these precautions were heeded.'

6. Conversion of systems to natural gas

57. Many of the persons who gave evidence to the inquiry, and indeed certain questions raised in the House, asked if the conversion operation had been correctly planned and executed. Three major points were raised:

Firstly, that the operation had been hurriedly planned and carried out at too great a speed.

Secondly, that the quality of manpower employed in the conversion was low.

Thirdly, that the training given to the workmen was inadequate.

58. Although at first sight these points may appear to be outside the terms of reference of this inquiry, incidents which had arisen soon after and apparently as a result of conversion had undoubtedly been interpreted by members of the public as reflecting on the safety of natural gas as a fuel. It therefore seemed desirable to include a detailed scrutiny of the procedures and problems involved in conversion of systems from town gas to natural gas.

59. The sequence of operations involved in conversion is outlined in Appendix 9. The following paragraphs discuss the validity of some specific criticisms which have been made, in the light of the evidence submitted to this inquiry.

60. No reasonable person can fail to admit that in an operation of this magnitude some human errors are unavoidable. It is fair to enquire, however, into the precautions which have been taken to foresee, to detect and to rectify such errors, and to ensure that they do not lead to unreasonable inconvenience to consumers or to actual danger.

61. It has therefore seemed appropriate to investigate comments from the public that the conversion operatives are not fully acquainted with the appliances to be converted; criticisms reported to have been made by gas fitters calling after conversion to check or correct maladjusted appliances; comments from the organizations representing skilled workers and managerial staff in the gas industry, relating to the adequacy of training of converters; and some allegations of lack of experience among conversion contractors. The problems presented by the conversion operation to appliance manufacturers have been discussed with them and with the staff at Watson House (Gas Council), where conversion sets are tested and if found satisfactory approved for use (see Appendix 10).

62. Evidence has been submitted by almost all the interested parties, several areas in which conversion was in progress have been visited and procedures and problems discussed with conversion personnel and members of the public. Different Area Boards have somewhat different procedures ; some employ contractors to carry out conversion while others employ their own labour force under the supervision of their own technical staff. In every case the conversion operation has been carefully planned over a long period. In most cases senior Board engineers had visited Holland and the U.S.A. to study previous experience of conversion in those countries, and the contractors had either been involved in conversion operations on the Continent or had been advised by American consultants. The provision of conversion sets was put in hand at an early date and most appliance manufacturers established special manufacturing groups for this purpose. All conversion equipment is tested and approved by the Gas Council (Watson House) before issue. Behind all this was the experience of the conversion of 7,000 consumers at Canvey Island in 1966 by the North Thames Gas Board.

63. No evidence has been found of any insurmountable difficulties, notwithstanding the complexity of the operation and the gradual build-up in size of conversion sectors. The conversion areas visited were adequately manned and efficiently organised. The use of computers for cataloguing and scheduling customers' appliances, etc., the maintenance of a complex stores and workshop service, and the obvious concern with priority cases such as old or handicapped customers, were all evidence of meticulous planning.

64. Contractors and Area Board officials employing their own manpower agreed that the response to advertisements for labour for conversion teams was far in excess of their expectations. In a typical case more than a thousand applications were received for four hundred vacancies, so that careful selection was possible. Selection procedures included both aptitude and character evaluation tests. The applicants were in the main of reasonable mechanical aptitude, frequently craftsmen from other industries (electricians, engineers, plumbers, etc.) and a substantial number had had previous experience in the gas industry. The quality and character of the men recruited has clearly been adequate for the task involved.

65. The recruits are trained in special schools established jointly by the contractors and Area Board Conversion Departments. The training schedule, which was carefully planned well in advance on an industry-wide basis by the Construction Industry Joint Training Board in collaboration

with the Gas Industry Training Board, comprises a three- to four-week basic training course in the conversion of simple appliances such as cookers and gas fires, and in some background skills. After passing a qualifying examination the trainee is assigned to a conversion team, where he works for several weeks under the direct supervision of an experienced conversion operative. Once he has shown his ability to work without supervision he is allowed to convert the simpler appliances and his work is checked by the senior conversion fitter. The best men are then given a further period of training in the conversion of more sophisticated apparatus, usually lasting one week. The operative is then returned to his conversion team to carry out the more difficult conversions and supervise junior members. Area Boards and contractors endeavour to keep each conversion team together as a working unit, and have found that after about twelve months most teams develop a remarkable degree of competence and pride in their corporate work. Working long hours together—usually 8 a.m. to 10 p.m. on the first day of a conversion operation—and the feeling of many younger operatives that they are in a new and worthwhile career are perhaps the main factors in this team spirit.

66. In giving evidence to this inquiry, officials of both the General and Municipal Workers' Union and the National Association of Local Government Officers testified to their current satisfaction with the quality of the conversion work force and the adequacy of training, and unreservedly withdrew earlier expressions of misgivings on these scores. These organizations and certain appliance manufacturers had earlier doubted the adequacy of supervision arrangements, but expressed confidence in the recommendations of the Gas Industry Training Board. Following assurances by supervisors and craftsmen that these recommendations were observed, these organizations withdrew earlier criticisms.

67. In each of the areas and with each of the contractors from which information had been received in this inquiry, the size of conversion sectors has grown until today sectors of 2,000 consumers are commonly converted in a single conversion cycle. A typical cycle is outlined in Appendix 9; the practice of Boards and contractors differs only in minor details apart from the preference of some Boards for the two-day cycle and others for the five-day cycle shown. A number of points in these procedures merit specific comment.

68. Some members of the public have expressed surprise that a trained conversion operative should spend time reading what appears to be a

simple set of instructions before proceeding with the conversion of an appliance, and have inferred that either training procedures or quality of personnel are inadequate. Such comments are based on a complete misconception of the nature of the conversion operation. The number of distinct types and models of domestic gas appliances in use in Great Britain is over 6,000, and the number of cooker models alone is over 1,500 (see Appendix 9). As regards those which can be converted on the consumer's premises, each model requires a different conversion kit, which is issued complete with a set of detailed instructions for the conversion operative. Since it is manifestly impossible for one individual to memorize in advance all the details involved in the conversion of every appliance he may encounter, he is specifically required to check each conversion set and read the instructions attached to it before starting the conversion.

69. On completion of the conversion the gas supply to the appliance and the primary air setting are checked by the operative and subsequently by his supervisor. Some Area Boards make further checks, insofar as they have skilled manpower available for the purpose. All exercise some measure of quality control over the conversion operation in this way—priority being given to central heating boilers and warm air units.

70. The conversion team is responsible for all 'call back' requests, complaints and queries from customers for several weeks after conversion, apart from reports of gas escapes which are dealt with immediately by the Board's normal service fitters. As experience has been gained by the teams, the number of 'call-backs' has fallen, and now stands at an average of about 20 per cent. of the number of appliance conversions. Some 10 per cent. of all call-backs, or 2 per cent. of the actual appliance conversions, require a second or further visit.

71. Following preliminary surveys of conversion areas by specialists from Watson House, a complete record of all call-backs and action taken has been prepared and analysed using a sophisticated computer programme.

72. A surprisingly large proportion (53 per cent.) involve maladjusted appliances—usually resulting in over-gassing or too large a flame. The simple explanation that the conversion operative and his supervisor had both failed to adjust the burner correctly seems unlikely, and it seems a more reasonable possibility that subsequent variations in gas composition (perhaps arising from inadequate purging of pipework), gas pressure (maladjustment of governors) or some effect of multiple appliance use on

the burners may have been involved. This high call-back figure for adjustment had led to much criticism of the conversion teams and may be associated with complaints made by consumers of excessively large flames. In some instances repeated visits by gas board officials have been necessary before the real cause of the defect has been isolated and corrected. Analysis of all call-back data by Watson House scientists has established certain patterns in such defects throughout the country and subsequent on-the-spot investigations have led to the correction or replacement of the critical appliance.

73. The professional competence of contractors and gas industry personnel in the detailed planning of conversion has been high. This inquiry has revealed nothing which suggests that conversion has not been well planned, fully understood and competently engineered and carried out. Most of the conversion contractors have been associated with the gas industry in the past, in connection with either appliance manufacture, distribution equipment or gas manufacturing plant, and have been either directly involved or in touch with conversion of systems to natural gas abroad. In every case the conversion contracting company has been able to draw upon the background skills of well organized major parent contracting companies.

74. Minor criticisms of failure of conversion sets, of wrong sets or of inadequate survey have been examined with two contractors. The highest level of error appeared to be about 1 per cent. in the first week of a conversion operation. It is clear that a certain number of human errors, inevitable in an exercise which has now converted over two million households, have slipped through the quality control checks operated by manufacturers, Area Board stores, and inspection procedures built in to the conversion teams' organization. Some faulty jets and broken burners have been fitted and have had to be replaced, but the number of complaints is not excessive and is much lower than has been experienced on the Continent.

75. There remains one area of complaint which appears justified and which may have a bearing on safety. This is the behaviour of pilot lights, flash tubes and electrical ignition devices, all of which are frequently found to be less reliable after conversion. The higher ignition temperature required with natural gas necessitates higher energy from the spark igniters and higher-voltage batteries in hot-filament igniters. The batteries can lose their efficiency fairly quickly. Failure to ignite, or delayed ignition, can lead to an accumulation of unburnt gas in, e.g. a cooker oven or

the combustion chamber of a central heating unit—followed by an explosion (fortunately usually a minor one but often alarming to the user) on ignition if the user does not turn off the gas and wait for the combustion space to clear before making a second attempt to light the burners. Inadvertent neglect of the fact that an oven burner has failed to light may lead to unburnt gas venting over the hot-plate and cause a flash-back to the oven. Vitiation by combustion products from a cooker oven may extinguish hot-plate pilots or even hot-plate burners. Turn-down and simmering conditions are also difficult to achieve with some appliances, although improved simmering burners for natural gas have now been introduced.

76. These difficulties are to some extent associated with the special characteristics of natural gas, but are mainly a matter of appliance design. Replacement of equipment which gives unsatisfactory performance by more modern burner heads, etc., could be made easier for the consumer with advantage.

77. From all the evidence received and from enquiries at all levels, it is concluded that the conversion operation for the whole country, as currently planned, is well within the capacity of the engineers, operatives and management and supporting staff available in the UK. Despite the errors which have occurred, there are certain major advantages arising from the conversion to natural gas which lead to greater safety of the whole system. These arise from the review and checking of all distribution systems and the sophisticated network analysis which precedes the conversion of a particular area, from the fitting of governors at the consumers' premises, from the pressure testing of all carcassing, from the survey of appliances and systems and from the reconditioning and replacement of appliances. These benefits, independent of any national economic benefit arising from the use of natural gas, are positive contributions to the safe use of gas and will result in a safer fuel system being available to the public.

7. Industrial and commercial applications

78. The problems associated with industrial equipment on conversion are different from those encountered in the domestic field. The reasons for this include the large size of the burner and the use of a multiplicity of burner ports (which ensures flame stability), the universal provision of flues and adequate combustion air (which removes the problems associated with vitiation) and the provision of better and more adequate controls to prevent the malfunctioning of the equipment. The main hazard on industrial equipment before and after conversion is the possibility of explosive conditions arising during the ignition period. Although natural gas is less easily ignited than town gas, the fact that all industrial applications are in large installations each individually designed by specialist engineers ensures that the problem of designing safe ignition systems is fully appreciated.

79. Commercial equipment has not been considered separately since it can be assumed that such equipment, from the safety point of view, is either large domestic or small industrial. The main hazards in this area are believed to be inadequate ventilation and flueing, and ignition, the possibility of explosions following incorrect lighting procedures being a greater hazard than in the domestic field.

Ignition in commercial and industrial applications

80. There are two aspects of natural gas combustion which make the lighting of burners more hazardous than with town gas ; these concern the greater difficulty in ignition referred to in Appendix 3 and the effects of lower flame speed and narrower limits of inflammability on the cross lighting characteristics.

Cross lighting

81. It appears to have been a common, though undesirable practice with town gas burners, when there were a number of burners firing into the same combustion space, to light only one of these burners directly and then to turn on the gas to the other burners and rely on the cross lighting characteristics of the gas to prevent a serious explosion. Evidence has also been given of other forms of malpractice involving oily rags or balls of newspaper being set alight and thrown into the combustion space. With town gas such practices did occasionally lead to explosions, but these were often not serious and usually the operator was able to ‘get away

with it '. Due to the lower cross lighting characteristics of natural gas such practices are likely to prove highly dangerous, and whilst the burners, if properly designed and installed, are capable of operating perfectly safely and satisfactorily, care must be taken to ignite each burner correctly according to the maker's instructions.

Ignition

82. The problems connected with the lighting of large burners are much the same on either town or natural gas. The essential problem is to avoid the accumulation of an explosive mixture of gas in the combustion space before ignition takes place. If the Codes of Practice and Standards for Automatic Gas Burners are followed in the design of automatic systems then there should be no problems. The current requirement of the 'double block and bleed' system for installations above 2 000 000 Btu/h could, however, be extended with advantage to installations of lower capacity.

83. If non-automatic burner systems are to be used then it is essential that all but the smallest systems be fitted with system interlocks to ensure that the operator follows the correct lighting procedure and that he is not able to take short cuts which could lead to dangerous situations. For example, it should be made impossible for the operator to open the main gas isolating valve unless all the main burner valves, on a multi-burner unit, are closed. It is also essential that the person responsible for lighting a large commercial or industrial burner should appreciate why a particular sequence of action is necessary, and that he should have had some training in light-up procedures.

84. It must be emphasized that natural gas does not involve new hazards in this field, but it does make some of the hazards existing with town gas more critical. It should also be stated that the inquiry has been presented with very little evidence of complaint of malfunction of commercial or industrial equipment converted to natural gas, and in certain instances the freedom of the gas from sulphur has proved a boon to particular industries.

8. Maintenance of appliances

85. One of the advantages of the conversion operation to the consumer is that the appliances which have been converted are cleaned, tested and left in good working order. During visits to conversion workshops and to consumer premises the attention of this inquiry has been drawn to the need for regular maintenance, particularly of sophisticated modern appliances such as central heating boilers and warm-air units. The latter, for instance, are frequently designed to operate in a relatively confined space, subjecting the electrical fittings to temperature fluctuations which are detrimental to the insulation, etc. Although these appliances are all subject to approval testing by Watson House, there is little doubt that after several years of operation they do deteriorate and may become unsatisfactory. Normally any electrical failure would result in shutting off the gas supply by the fail-safe devices which protect the equipment at all stages of the operation. However, in some instances, running repairs made by unqualified persons (frequently the occupant of the premises) have made the system unsafe, and dangerous overheating has resulted.

86. Central heating boilers also require regular cleaning and maintenance, not only to ensure the efficient operation of the boiler system but also to maintain safe conditions. Scale and soot on the heat exchanger surface can be dislodged and foul the burner ports, leading to incomplete combustion—the precursor of dangerous conditions.

87. The Gas Boards and the manufacturers of this type of equipment do offer attractive maintenance contracts and the majority of consumers avail themselves of such contracts. It would be desirable for safety reasons to extend the maintenance service to all consumers. Evidence submitted by appliance manufacturers shows that a maintenance contract which includes not only cleaning and checking the gas burning system but checking and replacement of all electrical equipment and fail-safe devices should result in an overall saving in costs to the user. Wider publicity of such figures would help to encourage consumers to keep their appliances efficient and safe. Discussions with Gas Board officials also indicate the need for regular maintenance, preferably on a contract basis. It is suggested that such maintenance should be offered as widely as possible, that all means of minimizing its cost should be explored, and that means be sought to offer special tariffs in particular circumstances. It would be unfortunate indeed if the contribution to safe use of natural gas made by the conversion operation were to be lost through lack of adequate maintenance.

9. Prospects for the future

88. One of the significant findings of the pre-conversion survey has been the large number of premises in which the Building Regulations concerning flues and the British Standard Codes of Practice concerning ventilation of rooms in which unflued gas burning appliances are used have been contravened or ignored. Reference has already been made, in the section on carbon monoxide poisoning from incomplete combustion, to the fact that reports available for study have indicated repeated instances of faulty flues, blocked or inadequate ventilation and in some cases absence of any ventilation whatsoever. Area Boards have also expressed concern at the conditions they are meeting in multi-occupancy buildings, particularly old houses converted into one-room flatlets at holiday resorts and in the overcrowded areas of some cities. A fatal incident in March 1970 illustrated the situation: a small bedroom heated by a non-flued gas fire had been redecorated and the ventilation brick covered by wallpaper.* In such a room lethal concentrations of carbon monoxide would be reached in a very short time irrespective of the nature of the gas being burnt. In slum areas in London instances of several gas cookers operating almost side by side on small upper floor landings have occurred. Many single-room flatlets have unflued instantaneous water heaters provided as the only means of hot water supply. Where, as is frequently the case, the only ventilation is provided by the opening of the window or door, the conditions are dangerous.

89. Consideration of this evidence suggests that some form of inspection is highly desirable. Certainly the gas authority should have the right to inspect premises in which it is believed dangerous conditions exist, and to cut off the gas supply until the conditions have been corrected. It would perhaps be unreasonable to ask the gas authorities to undertake compulsory inspection of all premises, as is believed to be the case in the Netherlands, not only because this would place a tremendous burden on the available manpower, but because it would produce a false sense of security. A flue which had been inspected and found satisfactory could become unsatisfactory immediately after inspection by blockage by a bird's nest, for example, or a room in which ventilation was found to be adequate could become inadequate by deliberate blocking of the ventilation brick by the occupant. However, it is clearly essential that the Building Regulations should be observed by all gas installation engineers and that the Building Inspector or the Gas Board should be advised and should ensure inspection of all new flues when fitted. Many in-

* A proposed addition to London Gas Undertakings Regulations, 1954 (Regulation No. 26) would prohibit this situation.

adequate flues have been fitted by unqualified persons who from ignorance of the Regulations have failed to notify the Building Inspector.

90. The gas industry has for some time advocated that all instantaneous water heaters in bathrooms should be flued or of the balanced-flue (room sealed) variety and lays particular emphasis on this requirement in the case of multipoint water heaters (i.e. those which are intended to supply hot water to several points in the premises, so that they are liable to be in more frequent use). It has also ceased to permit the sale or use of portable gas fires. However, flueless water heaters are still widely used and portable gas fires and unsatisfactory instantaneous water heaters can still be bought, for example on the second hand market. In many instances such appliances are bought and installed by the owner or occupier of the premises without recognizing the need for ventilation the use of such appliances involves.

91. Perhaps the only satisfactory method of dealing with these problems is by a well organized publicity campaign. However much of the evidence concerning safety in the home would indicate a similar need in respect of all fuels, including electrical systems. A joint safety committee of the fuel and energy supply industries could make a worth while contribution in this respect without requiring any one of them to finance separately a special campaign.

92. Throughout this inquiry the fact that in most premises the Gas Boards have not been involved in the supply or fitting of the internal carcassing has made difficult any investigation of the effect of unsatisfactory or inadequate pipework. Most modern buildings are provided with gas distribution systems to current BSI specifications, by competent and authorized gas installation engineers. Many older buildings have however a network of disused pipework, formerly leading to gas lighting systems. Most of these have been blanked off, but remain connected to the gas supply system and present a possible source of future leaks. The pressure-testing of the carcassing may not always have revealed conditions which would be potentially hazardous with the continued application of the higher pressures. In some instances recent installations have also been inadequate for the service demanded of them. Whilst it is true to say that piping suitable for town gas should be equally suitable with natural gas, the existence of potentially dangerous situations has evidently not always been recognized in the conversion operation. At present the responsibility for the safety of the internal system rests on the owner of the property and it is difficult to see what changes could be made to ensure the safety of the tenant or owner-occupier in the face of ignorance of the correct safe procedures.

93. On the general question of the undesirability of installation of gas equipment by unqualified persons, paragraphs 163 to 169 of the report of the recent inquiry into the collapse of flats at Ronan Point (HMSO, 1968) are of interest. In this report it is stated (para. 169) that 'it would certainly make for higher standards of safety if the fitting of gas appliances by all save Area Gas Boards or approved sub-contractors were prohibited, but we are doubtful if it would be reasonable or indeed practicable to enforce so rigid a form of control.' The creation of the Confederation for the Registration of Gas Installers (CORGI) (see Appendix 1), does bring into existence a voluntary associaton of gas installation engineers and the future operation of this body will be followed with interest. It has been accepted as necessary in the interests of public safety to establish through CORGI a register of qualified gas installation engineers and to provide a code of practice for their guidance, and this is being done. The installation of gas appliances and fittings by non-registered engineers could then be prohibited, or at least curtailed.

94. Another matter which is of interest in this connection, and which was also referred to, as a recommendation, in the report of the Ronan Point inquiry, is the possibility of a nation-wide statutory requirement for notification of installation of any gas appliance to the Area Gas Boards, such as is already in force in the Inner London area. It is understood that this possibility is receiving consideration by the responsible authorities.

95. These observations have no real bearing on the comparison of safety of natural gas and town gas. They are comments on the safe use of any gaseous fuel and are intended to emphasise the unsafe condition of many premises which the conversion survey has brought to light. It is hoped that due consideration will be given to these findings by the appropriate bodies.

10. Conclusions

96. The following is a summary of the conclusions reached in this inquiry, with references to the relevant paragraphs of the text of this report:

1. Natural gas can be stored, distributed and used with safety in correctly designed and properly maintained equipment.
2. Natural gas is non-toxic, and therefore its use in place of town gas will reduce and possibly eliminate poisoning accidents from unburnt gas (*paragraph* 12).
3. The use of natural gas does not increase the risks of fire and explosion. In correctly designed, installed, maintained and operated appliances natural gas can be used with safety by industrial, commercial and domestic consumers provided that the safety precautions which are necessary in the use of town gas continue to be observed (*paragraph* 36).
4. The use of natural gas does not increase the risk of carbon monoxide poisoning resulting from incomplete combustion, provided that appliances are correctly adjusted, have adequate provision for the supply of air for combustion, and have a correctly designed flue which is in a serviceable condition. In circumstances where inadequate flueing and faulty ventilation are present to the extent of giving potentially dangerous conditions with town gas, the use of natural gas may marginally increase the danger of carbon monoxide poisoning if, in addition, the appliance is improperly adjusted or has soot or corrosion products on heat exchange surfaces on which flames may impinge (*paragraphs* 48, 55).
5. No serious accident involving a domestic gas installation has come to the notice of this inquiry which was not associated with a combination of several of the factors referred to above, e.g. unserviceable condition or incorrect design, installation, maintenance or operation of an appliance or its associated pipework, flueing and ventilation systems.
6. The high-pressure bulk transmission system for natural gas in Great Britain has been designed, constructed and laid to the most exacting standards, and all possible safety precautions have been taken (*paragraphs* 24–26).
7. The surveys of medium-pressure and low-pressure distribution systems which have been and are continuing to be made as a preliminary to conversion to natural gas distribution, and the rectifica-

tion of faults and deficiencies consequent on these surveys, are increasing the reliability of the system and should lead to a reduced danger of gas leakage (*paragraphs* 27–29).

8. The governors used in the distribution system at all points at which it is necessary to control differences in pressure at the various stages, including the supply of gas from street mains to consumers' premises, are of a very high standard of design and quality and provide fully adequate protection of the system against sudden pressure surges (*paragraph* 32).

9. The surveys of consumers' appliances and installations which are made prior to conversion to the use of natural gas, and the consequent replacement of many unserviceable appliances and rectification of defective conditions, should lead to substantially higher levels of safety and efficiency in the use of gas, provided that consumers comply with the recommendations issued to them by the Gas Boards following these surveys (*paragraph* 77).

10. The conversion operation has been carefully planned, well organised and competently executed. The labour force available has been adequate in numbers and quality. The training programmes have been carefully designed and conscientiously carried out in accordance with the recommendations of the Industrial Training Boards (*paragraphs* 59–77).

11. The number of defects in conversion which have given rise to inconvenience and possible danger to consumers has not been excessive in relation to the size and complexity of the operation. In most cases they have been quickly rectified. The more difficult cases have been carefully analysed by the Gas Council's technical specialists. In most cases the source of the difficulty has been identified and effective steps taken to eliminate it (*paragraphs* 69–72).

12. The most serious dangers encountered in this inquiry are lack of adequate ventilation and flueing, especially the use of unflued appliances in unventilated rooms and unsatisfactory design and condition of flues. The majority of the cases examined have disclosed disregard or contravention of the Building Regulations with respect to flues and of the accepted Codes of Practice of the British Standards Institution concerning ventilation of rooms.

11. Recommendations

97. The recommendations which follow are to be taken as giving a general indication of the area in which it appears, from the evidence examined in this inquiry, that action is desirable. Their detailed implementation is outside the terms of reference of this inquiry, and it is appreciated that some of the matters referred to are already under consideration by the responsible authorities, and some modifications of existing regulations and practices are already in hand.

1. The provisions of the National Building Regulations and other legally enforceable controls for the provision, design and installation of flues and permanent ventilation should be strengthened.

2. The British Standard Codes of Practice relating to flueing and ventilation should be reviewed and extended to make them a suitable basis to support legislation.

3. In framing new regulations, particular attention should be paid to:

   i. Control of ventilation and flueing of gas appliances in small rooms.

   ii. Prohibition of the installation and use of gas appliances otherwise than as approved by the Area Gas Boards.

   iii. Notification to Gas Boards or Building Inspectors of intention to install or modify gas appliances and associated means of flueing and supply of combustion air, and inspection and approval of such installations by the Area Gas Board.

4. Gas Boards should have authority to enter premises and inspect gas installations, whether converted to natural gas or not, where they have reason to believe that dangerous conditions exist.

5. The attention of Local Authorities should be drawn to the desirability of inspection and testing of flues, to ensure that they comply with the standards of safety recommended by the Area Gas Boards.

6. In the event of such inspection revealing potentially dangerous conditions, the owner of the premises should be required to comply with the standards laid down by the Area Gas Board within a specified period; failing which, the Gas Board should be empowered to disconnect the supply of gas.

7. Every encouragement should be given to the Confederation for Registration of Gas Installers to proceed with the registration of qualified gas installers and the formulation of procedures for their guidance.

8. On completion of conversion of premises to the use of natural gas, Gas Boards should satisfy themselves in all cases that gas appliances are left correctly adjusted and that all gas appliances and associated equipment are in a fully satisfactory operating condition.

9. Area Gas Boards should seek by all available means to educate consumers as to the need for regular maintenance and servicing of gas installations in the interests of safety.

10. Public Health authorities should consider with the medical profession how best to ensure that the public are warned of the need to avoid vitiation of the air in inhabited rooms containing combustion appliances.

11. Consideration should be given to the formation of a joint safety committee of the fuel and electricity supply industries, to consider ways and means of promoting the safe use of fuel and electricity, particularly in the home.

12. All industrial gas burning equipment should be provided with means of checking that ignition is effective.

13. All commercial gas burning equipment should be provided with permanently displayed instructions for lighting.

14. Research should be directed by combustion appliance manufacturers and the fuel and building industries to improving the means whereby combustion air is supplied to fuel-burning appliances. It should be possible both to avoid discomfort from draughts and to ensure that the supply of air will not be obstructed by users.

FRANK MORTON.

22nd July, 1970.

L. J. JOLLEY,
Secretary.

APPENDIX 1

The organization and structure of the Gas Industry*

1. The present statutory structure of the gas industry differs little from that established at nationalization by the Gas Act, 1948, when over a thousand separate undertakings in Great Britain manufacturing town gas and distributing within comparatively small areas were grouped under twelve Area Gas Boards. The Boards are separate corporations appointed by the responsible Minister (formerly the Minister of Power, now the Minister of Technology) and separately responsible to him for the performance of their duties under the Gas Act.

2. The Minister is empowered under Section 67 of the Gas Act to make safety regulations. No regulations under this section have ever been made, because Ministers have been satisfied that the gas industry itself observes safety standards of a high order. Moreover, Section 55 of the Act provides for standards of gas quality, pressure and uniformity of calorific value to be complied with by Area Boards, and these standards involve considerations of safety, particularly those relating to quality and pressure. The Gas Standards Branch of the Ministry of Technology has the task of ensuring compliance with this section of the Act, and its duties include a general responsibility for safety.

3. The Gas Council, now consisting of five central members and the twelve Area Board Chairmen *ex officio*, advises the Minister, promotes efficient performance by the Area Boards, and plays an important co-ordinating role. In 1965 it was empowered to acquire and manufacture gas and supply it in bulk to the Area Boards, in order to facilitate the handling of natural gas.

4. The shape of the industry has changed since 1948 through rationalization of production and the establishment of high-pressure pipeline grids within each Area and, in recent years, by the construction of a nation-wide pipeline system to transmit natural gas. The availability of North Sea gas in very large quantities has radically altered the prospects of the industry. Government fuel policy since 1965 has called for rapid absorption of North Sea gas, resulting in accelerated growth of gas sales in existing and new markets. The Gas Council has assumed responsibility for acquisition and bulk transmission of natural gas and the direct supply of a few very large industrial consumers, and the Area Boards are responsible for marketing the major part of the gas, converting appliances to burn natural gas, phasing out manufactured gas and distributing natural gas directly to consumers as their basic source of supply.

* These notes cover briefly those aspects of the organization and structure of the gas industry which have a bearing on safety in the use of gas, particularly natural gas.

5. Further changes in the statutory framework of the gas industry have been proposed and were accepted in detail by Parliament in 1970*.

6. These included proposals that Gas Boards should have statutory authority to enter premises and inspect gas installations, flues and means of ventilation, and to disconnect and seal off appliances to cut off the gas supply where necessary in the interests of safety. Gas Boards are not empowered to take such action under the existing national legislation.

7. Consideration is also being given to making regulations under Section 67 of the Gas Act, 1948, to enforce approved standards of installation and maintenance, covering both materials and workmanship. Such regulations would be binding on Gas Boards, and on private firms and individuals concerned in the installation and maintenance of gas appliances.

8. To ensure that approved standards are everywhere understood and accepted, the industry has been encouraged by the Minister to set up a new voluntary association of appliance manufacturers, private installation contractors, and representatives of the gas industry itself, to organize and maintain a register of qualified gas installers. This organization has now been established with the title of the Confederation for Registration of Gas Installers (CORGI).

Consultative Councils

9. When gas was nationalized, provision was made for the appointment of a Consultative Council to represent consumers in each of the twelve Gas Board areas. The function of the Councils is to investigate complaints which consumers have not been able to resolve with the Boards and to provide means of bringing to bear the consumer's point of view on the Boards' general arrangements. Safety considerations are therefore a matter of particular concern to them.

Institution of Gas Engineers

10. The professional association of British gas engineers is the Institution of Gas Engineers, which provides a forum for the exchange of technical and scientific information at its research meetings and plays a major part through its various committees in the formulation of gas engineering standards, codes of practice and training procedures. It also acts as a link between British gas engineers and their counterparts overseas.

* A new Gas Bill for the reorganisation of the industry had reached the Report stage when its progress through Parliament was halted by the dissolution of Parliament in May, 1970.

International relations

11. The UK gas industry maintains close co-operative technological relations with its counterparts overseas through formal groups and informal contacts. The two main bodies through which collaborative research is carried out are the Groupe Européen de Recherches Gazières (GERG) of which the membership includes France, Italy, West Germany, Belgium, Holland and the United Kingdom, and the Atlantic Gas Research Exchange (AGRE) of which Gaz de France, the American Gas Association and the Gas Council are members. The Gas Council also supports the Groupe d'Etudes des Flammes de Gaz Naturel (GEFGN) and the International Flame Research Foundation (IFRF).

12. The major part in co-ordinating technological progress on the international level and developing international safety codes and standards of design, testing and approval of gas appliances and installations is played by the International Gas Union (IGU) on which 26 countries are represented. The British gas industry's link with the IGU operates through the Institution of Gas Engineers, and involves participation in a comprehensive system of standing technical committees and the organization of triennial conferences of gas engineers from all its member countries.

Research and development, testing and approvals organizations

13. The Gas Council maintains at Watson House, Fulham, a comprehensive organization for research and development concerned with domestic and commercial gas utilization, and with the testing and approval of domestic and commercial gas appliances of all descriptions. The Research Division is concerned with studies of the combustion characteristics of the gases sent out by the industry, the design of burners, flues and components of gas burning installations, and the establishment of procedures for testing the performance of gas appliances over the range of conditions likely to be encountered in use. The Testing and Approvals Divisions carry out tests of safety and performance on appliances submitted to them by manufacturers; subject to these tests appliances are given the Gas Council's seal of approval. Watson House has had the major responsibility for working out in collaboration with appliance manufacturers the detailed procedures for conversion of appliances, the provision of standardized conversion kits, and the training procedures for conversion operatives, and generally monitoring the technical details of conversion of appliances to natural gas. It also provides representatives of the British gas industry in the international committees concerned with efficiency, control and safety in domestic and commercial gas utilization.

A similar service is provided in the field of industrial gas utilization by the Gas Council's Midlands Research Station at Solihull at which the emphasis in safety considerations is mainly on ignition, flame failure and control devices.

The Gas Council's Engineering Research Station near Newcastle-on-Tyne is mainly concerned with pipeline engineering problems, including safety codes for the fabrication and testing of high-pressure steel mains, valves and ancillary equipment.

APPENDIX 2

Statistics of accidents attributed to the use of gas and other forms of energy

1. Accidental deaths attributed to gas in relation to total accidental deaths (England and Wales)

Year	Accidental deaths		
	Attributed to gas	Total from all causes	Gas cases as percentage of total
1963 . . .	1317	18 462	7·1
1964 . . .	964	18 577	5·2
1965 . . .	864	18 632	4·6
1966 . . .	851	18 891	4·5
1967 . . .	748	18 188	4·1

Source: Registrar General's Statistical Review for England and Wales.

2. Accidental deaths and serious accidents attributed to gas (all Area Boards)

Year	Poisoning by unburnt gas (deaths)	Poisoning by products of combustion (deaths and serious incidents)		Deaths from fires and explosions attributed to gas in dwellings	
				Town gas*	
		Town gas	Natural gas	Fire	Explosion
1963 .	1193	n.a.	nil	43	n.a.
1964 .	842	n.a.	nil	16	n.a.
1965 .	743	n.a.	nil	20	n.a.
1966 .	705	54	nil	31	3
1967 .	536	65	1	30	5
1968 .	369	86	4	37‡	5
1969 .	316†	82	7	n.a.	4

* None reported from areas supplied with natural gas.
† Provisional.
‡ No information available in this case as to whether natural gas supplied.

Sources: Registrar General's Statistics and Fire Research Station Statistics (Ministry of Technology and Fire Offices' Committee).

3. Fires attributed to the use of fuels and electricity (United Kingdom)

(The figures show the number of fires attributed to each fuel or source of energy as the source of ignition, per million therms supplied to final users.*)

*A. All fires in buildings**

Year	Gas		Liquid fuel§	Solid fuel‖	Electricity
	Public supply†	Propane and butane			
1963 .	1·32	5·2	0·86	0·31	4·11
1964 .	1·32	5·5	0·54	0·25	3·98
1965 .	1·18	4·0	0·49	0·24	3·77
1966 .	1·23	4·2	0·46	0·23	3·81
1967 .	1·21	4·8	0·43	0·23	3·95
1968 .	1·26	4·3	0·43	0·24	4·02

B. Fires in dwellings

Year	Gas		Liquid fuel§	Solid fuel	Electricity
	Public supply	Propane and butane (bottled gas)‡			
1963 .	1·68	6·3	4·94	0·49	6·36
1964 .	1·85	5·3	3·52	0·41	6·39
1965 .	1·52	3·9	3·31	0·38	6·06
1966 .	1·52	4·8	3·29	0·30	6·22
1967 .	1·58	8·2	3·24	0·37	6·59
1968 .	1·58	6·9	3·27	0·39	6·78

* Fuels used in agriculture, rail, road, water and air transport are excluded, as also are fuels used for conversion to secondary or processed fuels (e.g. in power stations, gas works, oil refineries, etc.).
† In Table A only, includes coke oven gas used in iron and steel and other industries, apart from internal use.
‡ In Table B, does not include bottled gas supplied to some outlying areas by Gas Boards. Any misreporting of such cases by Fire Brigades might lead to a slight overestimation of the number of fires due to bottled gas
§ Excluding liquefied petroleum gases.
¶ In Table A, coke used in blast furnaces is excluded.

Sources: Fire Research Statistics (Ministry of Technology and Fire Offices' Committee) and Ministry of Power Digest of Energy Statistics, 1968–1969.

APPENDIX 3

Properties of town gas and natural gas

1. In comparing the chemical and physical properties of town gas and natural gas it is essential to realize that there is no single gas representative of 'Town Gas' nor, for that matter, a single 'Natural Gas'. A whole range of gases exists, some of which may be broadly joined together into groups which have similar characteristics.

2. In order to group gases in this way it is usual to take into account a few of the basic physical properties which have been found to control the burning characteristics of the gas. The most important of these are the *gross calorific value* (expressed as Btu/ft^3, the volume being measured at 30 in. mercury pressure and 60°F with the gas saturated with water vapour) and the *specific gravity,* which is the density of the gas compared to that of air under the same conditions. If the calorific value is divided by the square root of the specific gravity, the resultant factor is known as the *Wobbe number* which indicates the amount of heat which is available from the gas flowing through a given sized orifice under a given mains pressure. Before the advent of natural gas, manufactured town gas was grouped according to a range of Wobbe numbers as follows:

Gas group	*Wobbe number*
G3	800 ± 40
G4	730 ± 30
G5	670 ± 30
G6	615 ± 25

3. In Table 1, a number of typical town gases are listed together with some of their principal properties, and it will be seen that most of these gases fall into group G4. In Table 2, which has been included for comparison purposes only, a number of other manufactured gases are listed. These gases all have quite low Wobbe numbers and, with the possible exception of the last listed (which is a G6 gas), would not normally have been distributed without enrichment. Table 3 lists some of the relevant properties of natural gases, and it can be seen that all the gases used in Great Britain have Wobbe numbers of around 1300 and, in fact, the natural gas which is being distributed in Great Britain is specified as having a Wobbe number of 1335 ±5 per cent. (1335 ±65).

4. Comparison of Tables 1 and 3 indicates that natural gas has a much higher calorific value than town gas and thus, to obtain the same heat release from a burner, only about half the volume of natural gas has to be burnt compared with town gas.

5. In Table 4 some of the other relevant properties of the two groups of gases 'G4 Town Gas' and 'Natural Gas' are given. It will be realized that these

are averaged values and that some variation on the quoted values will be found amongst different gases within the group. The importance of the remaining properties in Table 4 is discussed below*.

Burning velocity

6. The maximum burning velocity of natural gas is about half that of the hydrogen-containing town gases. The main effect of burning velocity on the burning characteristics of a gas is on its tendency to 'lift'. This means that the flame of a slower burning gas is more liable to lift off the burner, and go out, than a faster burning gas, and it is hence more difficult to stabilize a natural gas flame. In practice this has meant that it has so far not proved possible to design non-aerated burners for natural gas, although it should be noted that several designs have been proposed and research continues. Even aerated burners, which have a lower efflux velocity and are somewhat easier to stabilize, still suffer from flame lift, and this remains a problem with natural gas burners.

Limits of inflammability

7. These are defined as the lower and upper limits of gas concentrations in air mixtures between which the gas can be ignited. Lower concentrations of gas in air (lean mixtures) will not ignite, nor will higher concentrations (rich mixtures). It will be noted that the limits of inflammability are narrower for the natural gases than for the G4 gases, and this may be an important safety point in favour of natural gas when considering the dangers from explosion, and will be considered further under this heading. The main effect on burning characteristics is to reduce, if not eliminate, the danger of light-back when burning natural gas. The phenomenon is familiar with town gas where, except at quite low amounts of primary aeration, the flame can, under certain conditions, enter the burner tube and 'light back' to the gas jet. With natural gas, however, even at 60 per cent. primary aeration the air/gas mixture in the burner tube will not burn and the burner will not light back. (This is illustrated by the figure quoted for 'gas in mixture at 50 per cent. primary aeration' in Table 4). The same phenomenon, however, makes the design of flash tubes for ignition purposes more critical, and this will be discussed under the heading of 'Ignition'.

Air required for combustion

8. The amount of air required to oxidize the fuel completely to carbon dioxide and water is known as the 'stoichiometric quantity', and this has been calculated for all the gases listed in Tables 1, 2 and 3. The average values given in Table 4 show that, for the same heat release, natural gas requires on the average about 7 per cent. more air than town gas. However, the variation between the gases, particularly within the town gas group, is quite large, the values for town gases in Table 1 ranging between 8·4 and

* In some of the tables the properties of dry pure methane and dry commercial propane and butane are given for comparison purposes.

9·0 ft^3, and those for British natural gases in Table 3 being almost constant at about 9·4 ft^3. Thus the difference between the air requirements of town gas and natural gas is between 4 per cent. and 12 per cent.

Carbon monoxide content

9. Natural gas contains no carbon monoxide and is non-toxic. Town gas, however, contains varying amounts of carbon monoxide ranging from 2·5 to 15·5 per cent. for the G4 gases in Table 1 while carburetted water gas contains about 30 per cent. and 'blue' water gas (Table 2) contains 41 per cent. of carbon monoxide. Any gas containing carbon monoxide presents a potential hazard to life by accidental or deliberate posioning. With gases containing less than 5 per cent. carbon monoxide this hazard is not very serious and has been accepted for years as a reasonable compromise. Gases containing more than 10 per cent. carbon monoxide are definitely dangerous and such gases are no longer distributed in Great Britain (cf. also Appendix 7).

Sulphur content

10. Natural gas as distributed in Great Britain contains very little sulphur, although a trace is added in the form of an odorant. Coal gas and water gas, however, contain appreciable amounts of sulphur compounds. This does not normally create a hazard, although it may lead to corrosion and fouling of heat exchange surfaces and blockage of internal flue ways in water heaters and central heating boilers. The virtual absence of sulphur in natural gas is a definite advantage.

Volume of flue gas produced

11. Although natural gas uses about 7 per cent. more air for combustion than town gas, it will be seen from Table 4 that on the average the amount of extra flue gas produced for a given heat release is only 2 per cent. greater. The figures are given in more detail in Table 5, where the variation between individual gases in a given group shows that G4 gases produce from 9·80–10·50 ft^3/1000 Btu and British natural gases from 10·31–10·46ft^3/1000 Btu. Thus the variation is from about 7 per cent. more to about 2 per cent. less flue gas with natural gas as compared with town gas. It can also be seen that some of the other manufactured gases produce very much more per 1000 Btu than do G4 gases, and also that Dutch and French natural gases produce a rather greater volume of flue gas than do the British natural gases.

Volume of carbon dioxide produced

12. It could be expected that the danger of carbon monoxide production in the atmosphere when gas is burnt under incorrect conditions would be directly related to the amount of carbon in the gas. In order to assess the carbon content of all the gases studied on an equal heat input basis the volume of carbon dioxide produced per 1000 Btu has been calculated and is reported

in detail in Table 5. For British natural gas and G4 town gas it can be seen that the figures are almost identical although, as might be expected, water gases and producer gases do yield an appreciably greater amount of carbon dioxide than the other gases.

Operating chacteristics

13. The chemical and physical properties of gases discussed above provide a sufficient background for the understanding of some of the basic differences in distribution practice and performance characteristics of town gas and natural gas.

Burner pressure

14. For a given heat output from a burner, consideration of the calorific value shows that the volume of natural gas required for a given heat output is one half that of town gas, but that approximately the same amount of air must be used in both cases. From consideration of vitiation and flame stability it is desirable to entrain as much as possible of this air as primary air, but consideration of the light-back characteristics of aerated burners indicates that primary aeration should be below 50–60 per cent. It is also advantageous for the conversion operation that the size and performance of any new burners for natural gas should be similar to those for town gas and if possible the same overall size of burners should be used for both gases. The *Gas Modulus* (the square root of burner pressure divided by the Wobbe number) provides a useful parameter for determining burner performance and for equal performance on different gases it should be kept constant. Hence if a G4 gas with a Wobbe number of 740 was distributed to the burner at 2·5 in water gauge (w.g.), natural gas with a Wobbe number of 1335 should be available at a pressure of $\left(\sqrt{2{\cdot}5} \times \frac{1335}{740}\right)^2$ or 8·2 in w.g. (Actually since about 7 per cent. more air is needed by the natural gas the pressure ought to be a little higher.) Thus to obtain similar performance on converted equipment a gas pressure of at least 8 in w.g. has to be used.

15. Similar practice has been adopted abroad. France and Germany have used 8 in w.g., Holland has gone higher to 10 in w.g., whilst in the USA, where lower pressures were formerly used, there is now a trend towards 8 in w.g. In Australia a lower pressure of 4·5 in w.g. has been widely adopted. This does have the advantage of reducing the noise produced by the burner, but has necessitated extensive redesigning of burners and the 'down-rating' of many appliances.

Ignition

16. It is not possible to give exact figures for the energy required for the ignition of gas flames. However, it is generally agreed that it is rather

more difficult to ignite a natural gas (i.e. methane) flame than it is to light a flame of a gas containing hydrogen. There are a number of reasons for this, related to the narrower inflammability limits and the energy required for ignition. If the energy source is a flame produced either by a match, a pilot light or a gas torch there is little problem, since a flame produces many times the minimum energy required and occupies a comparatively large volume with a large surface area and, provided such a flame is in approximately the correct position relative to the burner, ignition will take place. With electrical ignition, however, positioning has to be sufficiently accurate for the igniter to be in contact with the gas/air mixture within the inflammability limits, and both the temperature and the energy release must be sufficiently high. These requirements apply to any gas, but gases containing hydrogen in contact with incandescent metal filaments undergo a surface catalytic reaction which effectively raises the temperature so that the flame will be ignited at a rather lower energy release than appears theoretically to be required. Thus to ignite a methane/air flame from a filament type igniter, higher voltages are required. Spark ignition, whether provided by mains electricity, magneto or piezo electric crystal, should be equally effective for town gas or methane, but the position of the igniter is more critical.

17. One of the most popular ways of providing ignition of, for example, cooker hot plates, is by use of 'flash-tube' ignition from a permanent pilot flame. This has been in general use in town gas cookers since 1959, and although not entirely trouble free it has given a high standard of performance and reliability when properly maintained. The design of flash-tube ignition systems for methane is more critical and in some countries it has been decided to abandon their use for the time being. However, there is no reason why, with correct design and installation, flash-tube ignition should not be retained. The main requirement appears to be an increase in diameter of the tube from $\frac{3}{8}$ in to $\frac{1}{2}$ in to prevent smothering of the methane flame. The adjustment appears to be more critical and it seems likely that maintenance may be even more necessary.

Explosions

18. Any combustible material if mixed with oxygen in the correct proportions can produce an explosive mixture, and serious explosions have been known to occur by the ignition of dusts of, for example, flour and soot. All fuel gases, when mixed with air, can therefore produce explosive mixtures and if ignited explosion will occur, the force of the explosion being related to the total energy release, the volume of the explosive mixture and the degree of confinement of the explosion. The latter is important since if the mixture is not confined in any way it will be free to expand normally and the only effect will be of a flame front passing through the mixture. However in a confined space the pressure in the gas will build up, and then, if the walls are ruptured by the increased pressure, not only will this damage the structure, but the rapid expansion of the confined gas may cause further damage. It

is common industrial practice to build into an apparatus which may contain explosive mixtures a weak part of the walls or roof which will collapse readily or cause an 'explosive relief'. A similar situation can arise in normal rooms where a window or door can 'blow out' and limit further pressure build-up or actual structural damage. In order to assess the relative hazards of town gas and natural gas in explosive situations it is thus necessary to consider several of the properties of the gases, as attempted below under the following headings:

i. Likelihood of forming an explosive situation.

ii. Likelihood of ignition of such a mixture.

iii. Total energy release for a given volume.

iv. Final total pressure rise in a confined space.

v. Maximum pressure rise in a space containing an explosion release.

Formation of explosive mixture

19. An explosive mixture can only exist when its composition lies within the inflammability limits. These are given in Table 4 as 5–15 per cent. by volume for natural gas/air and 4–40 per cent. for G4 town gas/air. The difference at the lower limit is negligible. Thus at this 'lean' end approximately the same volume of either gas in air will be dangerous. At the upper limit however a 'rich' mixture of natural gas/air with more than 15 per cent. natural gas *will not ignite*. With town gas such mixtures will ignite with up to 40 per cent. gas in air. Thus the likelihood of an explosive mixture forming with natural gas is less, but it is probable that in practice 'lean limit' explosions are the more common.

Ignition of an explosive mixture

20. As stated earlier natural gas/air mixtures are more difficult to ignite, but again, in practice, the energy of ignition sources likely to be encountered is probably sufficiently high in any case for this point not to be of great importance.

Energy release

21. When considering total energy release from a given volume the immediate assumption might be that since natural gas has double the calorific value of town gas the explosion will release twice the amount of energy. This is *not* the case. For energy to be released the fuel must be oxidised by the atmospheric oxygen and the maximum energy will be released when the composition of the mixture is such that when every molecule of the fuel has been completely burnt to carbon dioxide and water there is no excess oxygen left after the explosion. This composition can be readily calculated from the chemistry of

the reaction and the mixture is called a stoichiometric mixture. If the energy released for equal volumes of a stoichiometric mixture of natural gas and town gas is calculated, it is found to be almost identical in the two cases (because a stoichiometric mixture of natural gas/air contains only about half as much gas as a similar mixture of town gas/air). At the lean end it is true that the energy release per unit volume of natural gas is greater than with town gas, but in such cases the total energy release is much less than the maximum.

Final pressure in a confined space

22. For a stoichiometric mixture in confined space, as the energy release is about the same and the products of combustion are of approximately the same volume (see Table 4), the final pressure must be nearly the same in the two cases.

Maximum pressure rise in a space containing an explosive relief

23. Town gas which contains hydrogen burns faster than natural gas which does not. This means that not only does the flame front in a stoichiometric mixture travel faster in town gas, but that the mixture is more likely to pass from laminar to turbulent burning (with a consequent even more rapid rise in pressure). In a confined space this simply means that the final pressure is reached sooner. But if there is an explosive relief, which vents after a given pressure is reached, the situation becomes more complex. The main factor is that it requires a small, but finite, time for the relief to give way and for venting to occur. During this time the faster burning gas will give a considerably greater pressure rise than will the slower burning gas, and since this pressure is above that for which the relief was designed, it is during this period that structural damage may occur. Thus it seems possible that under such conditions town gas may create a greater hazard than natural gas.

24. However, although it might be deduced from the above that town gas presents a greater hazard than natural gas in explosive situations much work still needs to be done and at present it is probably unwise to infer that natural gas is significantly less hazardous.

Effect of vitiation of combustion air

25. The term vitiation implies contamination or impairment of quality. It is used in this context to mean a reduction in the oxygen content of the combustion air by contamination with either products of combustion (carbon dioxide and water) or with water vapour (as in a bathroom or kitchen). The effect of such vitiation, however caused, is to lower the partial pressure

of the oxygen in the combustion air and this means that a larger volume of vitiated air is needed to supply the oxygen necessary to burn a given quantity of gas than would be needed if the air were not vitiated. A complete account of the effect of vitiation on gas flames is beyond the scope of this report, but the general effects are to lower the flame temperature, to lower the burning velocity and to narrow the limits of inflammability. As has already been discussed, burning velocity affects the stability of a flame and lowering of the burning velocity makes a flame more liable to lift. However the main effect of vitiation is to lengthen the flame envelope. This is to be expected since the larger quantity of gas/air mixture must occupy a larger volume, particularly when burning at a lower flame speed. If the flame is burning freely inside a room, the initial effect of vitiation is to lengthen the flame (with no change in the composition of the combustion products—only carbon dioxide and water being formed). This lengthening will continue until the flame becomes unstable and begins to 'lift' (at this stage carbon monoxide may appear in the combustion products). Eventually the flame will be extinguished. The differences between town gas and natural gas are mainly that the natural gas flame starts to lengthen at a lower level of oxygen depletion than the town gas flame, that it will lift a little earlier and that it will go out rather sooner, but it is doubtful if under these conditions, with a free burning flame, there is a significant difference between the two gases.

26. When the flame is confined inside an apparatus two additional factors arise; these are (*i*) a restriction in the supply of secondary air, and (*ii*) the possibility of flame impingement either on other flames or on cool surfaces. In these cases the products of combustion are more likely to contain carbon monoxide than under a similar level of oxygen depletion in the free standing flame. A comparison between natural gas and town gas flames under these conditions is complicated by the need to consider the design of the apparatus and only general considerations can be dealt with here.

i. Restriction of supply of secondary air

Since approximately the same amount of air is required by the two gases, there is probably little difference between them in this respect. However, the use of aerated burners with natural gas lessens the amount of secondary air needed compared to a non-aerated burner and this might be considered an advantage. Against this must be set the larger volume occupied by the aerated burners themselves, and the consequent restriction in the passageways supplying the secondary air.

ii. Flame impingement on other flames or on cool surfaces

(*a*) If two flames impinge on each other the total area available for oxygen diffusion is reduced. This results in a considerable lengthening of the combined flame and increases the chance of impingement on cooled surfaces with the consequent release of carbon monoxide into the flue gases. There is probably little difference in the behaviour of the two gases in this respect.

(*b*) If a flame impinges on a cooled surface the combustion reactions will be halted. There is some debate about the speed at which the reaction will be quenched and whether the consequent increase in carbon monoxide level in the flue gas is due to 'freezing' the equilibrium of the $CO+\frac{1}{2}O_2=CO_2$ reaction, to lowering the flame temperature so that further oxidation of the carbon monoxide is prevented, or to the presence of the solid surface reducing the area available for oxygen diffusion. The actual mechanism of the process by which carbon monoxide increase occurs in these circumstances is of less importance to this inquiry than the fact that it does take place. There is no evidence that the two gases differ in the amount of carbon monoxide produced on flame impingement. The carbon content, as measured by the amount of carbon dioxide produced per 1000 Btu, is the same for the two gases, and on this basis no difference in behaviour would be expected. However, if the natural gas flame lengthens earlier, then impingement would occur at rather lower levels of vitiation and this would make the design of the combustion chamber more critical. If the same combustion chamber is to be used (on, for example, an instantaneous water heater) after conversion to natural gas it may be necessary to down-rate the apparatus in order to prevent flame impingement when burning vitiated air. However, with correctly designed or correctly converted apparatus there appears to be no reason why natural gas burning under vitiated conditions should give rise to a greater hazard than town gas. It should perhaps be emphasized that vitiation is itself a fault and except when occurring to a minor extent on cooker hot plates or grills or in Se-duct systems,* implies a blocked or inadequate flue and/or the absence of correctly installed ventilation.

* *Se-duct:* A type of common flueing system for high-rise multiple apartment buildings. The gas appliances are room-sealed and all take their combustion air from a common vertical duct, into which the products of combustion are also discharged. In these systems the combustion air is necessarily vitiated, and the appliances have to be of suitable design to cope with this.

TABLE 1

Analysis and properties of typical town gases (Gas Council)

Gas	H_2	CO	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_nH_m	CO_2	N_2	O_2	Calorific value Btu/ft³ Sat	Specific gravity	Wobbe number Sat	Air required ft³/100 ft³	Air required ft³/1000 Btu
Traditional coal based	51·0	14·6	19·1	1·7	0	0	3·5*	3·6	6·1	0·4	500	0·47	730	439	8·8
Carburetted water gas.	37·0	30·5	12·6	1·4	0	0	7·0†	5·6	5·5	0·4	500	0·63	630	436	8·7
Lowpressure reformed naphtha+CH_4 enrichment .	44·3	15·5	29·0	0·2	0	0	0·1*			6	500	0·48	720	420	8·4
Reformed CH_4+CH_4 enrichment	49·7	2·9	27·6	2·2	0·6	0					500	0·478	724	450	9·0
ICI 500 .	48·9	2·7	33·6	0	0	0					500	0·470	730	443	8·95
Gas recycle hydrogenator+ICI	56·5	2·9	18·9	6·7	0	0					500	0·470	730	442	8·83
Catalytic rich gas+ICI .	48·0	2·5	34·1	0	0	0					500	0·480	720	445	8·9

% From cal

Average air required 8·8 ft³/1000 Btu

TABLE 2 *Analysis and properties of gas produced by conventional solid fuel gasification*

Gas	H_2	CO	CH_4	C_nH_m	CO_2	N_2	O_2	Calorific value Btu/ft³ Sat	Specific gravity	Wobbe No. Sat	Air required ft³/100 ft³	Air required ft³/1000 Btu
Producer gas:												
coke	10·6	27·3	0·4	—	5·7	56·0	—	125	0·90	132	94·3	7·55
coal	16·1	30·0	2·6	—	3·4	47·7	0·2	173	0·83	190	134	7·75
Blue water gas:												
coke	50·0	41·0	0·5	—	5·0	3·5	—	295	0·54	401	222	7·52
Semi-water gas:												
coke	38·0	32·5	0·5	—	6·0	23·0	—	230	0·66	283	173	7·52
Conventional total gasification gas:												
coal	52·2	28·5	6·5	0·6	8·0	4·0	0·2	335	0·52	465	267	7·97
coal and oil	40·0	27·2	11·8	6·8	7·0	7·0	0·2	485	0·63	611	419	8·65

Source: 'Gasmaking' (British Petroleum Co. 1965), p. 31.

TABLE 3

Analysis and properties of natural gases (Gas Council)

Source	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	CO_2	N_2	H_2	CO	Calorific value Btu/ft^3 (dry)	Specific gravity	Wobbe No. (dry)	Air required ft^3/100 ft^3	Air required ft^3/1000 Btu
Britain (UK and North Sea)														
West Sole (Rotliegendes)	94·1	3·2	0·6	0·2	0·2	0·5	1·2	0	0	1041	0·593	1352	980	9·40
Hewett (Lower Bunter)	91·9	3·9	0·9	0·4	0·5	0	2·4	0	0	1060	0·609	1358	994	9·38
Hewett (Upper Bunter)	81·8	6·0	2·5	0·4	0·2	0·1	9·0	0	0	1020	0·653	1262	960	9·40
Indefatigable (Rotliegendes)	91·8	2·9	0·5	0·2	0·2	0·7	3·7	0	0	1012	0·604	1302	950	9·40
Leman Bank (Rotliegendes)	94·8	3·0	0·5	0·2	0·2	0	1·3	0	0	1041	0·587	1359	978	9·38
Lockton (Magnesian Limestone)	93·7	2·6	0·4	0·2	0·2	0·3	2·6	0	0	1024	0·593	1330	960	9·40
										Average air required 9·4 ft^3/1000 Btu				
Algeria														
LNG . . .	87·7	8·6	2·3	0·9	0·1	0	0·4	0	0	1132	0·634	1422	1063	9·38
LNG and Lean Gas	66·6	11·6	3·9	1·7	0·1	2·8	0·3	12·6	0·4	1081	0·643	1350	1006	9·32
Holland														
Groningen . .	81·7	2·7	0·4	0·1	0·2	0·9	14·0	0	0	896	0·644	1117	840	9·35
France														
Lacq . . .	82·1	3·3	1·0	0·7	1·1	11·6	0·2	0	0	980	0·723	1152	925	9·43
USA														
New York Supply	94·5	3·3	0·7	0·3	0·2	0·7	0·3	0	0	1049	0·595	1360	988	9·43
USSR														
Moscow Supply .	93·2	0·7	0·6	0·6	0·5	0	4·4	0	0	1006	0·605	1295	951	9·43
Pure methane (For comparison)	100	—	—	—	—	—	—	—	—	1012	0·553	1370	950	9·55
Commercial propane (For comparison)	—	—	92·5	2·5	(C_3H_6: 5·0)	—	—	—	—	2520	1·47	2076	2380	9·62
Commercial butane (For comparison)	0·1	7·2	0·5	87·0	C_3H_6: 4·2	C_4H_8: 1·0	—	—	—	3106	1·96	2219	2940	9·65

TABLE 4 *Characteristics of G4 town gas and natural gas*

	Town gas (G4)	Natural gas	Ratio NG/TG
Calorific value (Btu/ft^3)	500	1020	2·0
Specific gravity	0·475	0·584	1·2
Wobbe number	730	1335	1·8
Maximum burning velocity (cm/s)	80 (approx.)	35	0·4
Limits of inflammability (per cent.)	4–40	5–15	—
Gas in mixture at 50 per cent. primary aeration (per cent.)	31·7	17·3	—
Air required for complete combustion/1000 Btu (ft^3)	8·8	9·4	1·07
CO content (per cent.)	3–20	0	—
Sulphur content (lb/10^6 ft^3)	0·5–40	0·2–0·8	—
Volume of flue gas/1000 Btu (ft^3)	10·2	10·4	1·02
Volume of CO_2/1000 Btu (ft^3)	1·01	1·00	0·99
Burner pressure (in w.g.)	2·5	8·0	3·2

TABLE 5 *Flue gas produced (stoichiometric mixture) and volume of CO_2*

		Volume of flue gas		Volume of CO_2	
		Per 100 ft^3	Per 1000 Btu	Per 100 ft^3	Per 1000 Btu
Town gases					
Traditional coal based		498	9·96	51·2	1·02
Carburetted water gas		495	9·90	69·0	1·38
LP reformed naphtha+CH_4 enrichment		490	9·80	50·0	1·00
Reformed CH_4+CH_4 enrichment		525	10·50	49·0	0·98
ICI 500		517	10·34	51·1	1·02
Gas recycle hydrogenator+ICI		516	10·32	51·7	1·03
Catalytic rich gas+ICI		520	10·40	52·0	1·04
Producer gas	coke	175	14·0	33·4	2·67
	coal	211	12·2	36·0	2·08
Blue water gas	coke	276	9·35	46·5	1·57
Semi water gas	coke	238	10·3	39·0	1·70
Conventional total	coal	327	9·76	44·8	1·34
gasification gas	coal and oil	487	10·0	72·8	1·50
Natural gases					
Britain					
West Sole	Rotliegendes	1083	10·40	104·6	1·00
Hewett	Lower Bunter	1094	10·31	106·5	1·00
	Upper Bunter	1066	10·46	104·0	1·02
Indefatigable	Rotliegendes	1053	10·40	101·6	1·00
Leman Bank	Rotliegendes	1080	10·36	104·1	1·00
Lockton	Mag Limestone	1062	10·38	102·2	1·00
Others					
Algerian	LNG	1172	10·36	115·9	1·02
	LNG+Lean Gas	1112	10·29	112·0	1·03
Holland	Groningen	1042	10·62	90·6	1·01
France	Lacq	1039	10·58	111·6	1·14
USA	New York Supply	1092	10·43	106·1	1·01
USSR	Moscow Supply	1055	10·48	101·3	1·01
Other Fuel Gases					
Pure methane		1050	10·56	100·0	1·00
Commercial propane		2580	10·43	320·5	1·22
Commercial butane		3176	10·40	380·6	1·25

APPENDIX 4(a)

High pressure bulk transmission system

1. Natural Gas from the North Sea is brought ashore at two points on the East Coast and after a certain amount of treatment to remove any water or higher hydrocarbons which might condense in the distribution system, it is metered and odorized and is fed into the high pressure bulk transmission network. This high pressure pipeline network is designed to distribute natural gas at pressures from 550 p.s.i. up to 1000 p.s.i. It is based on the original 'backbone' main commissioned in 1964 to distribute Algerian natural gas from the Canvey Terminal to eight Area Gas Boards. The system consists of all-welded steel pipe of up to 36 in diameter and is built and laid to very high standards. Although new lines are mostly of 36 in diameter the original 'backbone' main was 18 in with branches varying from 6 in to 14 in and the first feeder main from Easington was 24 in diameter. This transmission network is still being built but when completed it will allow natural gas to be supplied to all the twelve Area Boards for further distribution on the medium pressure system.

2. Because some energy is required to move the gas along the line the pressure is less at points remote from the terminal and a number of pressure booster stations are required in order to make the best use of the carrying capacity of the pipeline.

3. Since the relative safety of such a system depends on its design and construction, some of the main points which have been studied in detail by the inquiry are summarized below.

i. General construction

The lines are designed for operation at pressures of up to 1000 p.s.i.; they are of all-welded construction using either seamless or longitudinally welded steel pipe and are laid by the normal 'pipeline spread' method used for all long distance cross country lines throughout the world. The lines are always buried at least 3 ft deep, except at terminals, off-takes and booster stations. The lines are constructed of special high tensile steel supplied to particularly high specifications. All joints are butt welded and all welds are subjected to exhaustive X-ray or gamma-ray testing, with some supplementary use of ultrasonic tests. The lines are protected from corrosion both by a coal-tar enamel and fibreglass coating, and by cathodic protection using sacrificial anodes during construction and impressed current after completion. On completion the line is hydraulically pressure tested to just above the specified minimum yield point (this is about twice the maximum operating pressure of 1000 p.s.i.) for 24 hours. Such high level testing is a comparatively new development, but a similar procedure with a typical North American pipeline company has resulted in no service failures in several thousand miles of pipe over a period of years since completion.

ii. *Additional precautions in certain areas*

The pipeline is particularly vulnerable to damage when it has to cross lines of communication (roads, railways, rivers and canals). It should perhaps be mentioned here that there has, to date, been no serious incident on any of the Gas Council's completed pipelines and in designating any area as hazardous account has been taken of overseas experience with lines not built to the present standards. At all rail and road crossings the pipe is sleeved inside a second pipe of rather greater diameter. The annulus between the pipe and the sleeve is either sealed and pressurized with dry nitrogen to 15 p.s.i., or the annulus is completely filled with a specially compounded grout. The sleeve is electrically insulated from the pipeline, and is protected against corrosion in the same way as the pipeline. Such sleeving is used at all crossings and is extended for 50 ft on either side of the crossing boundaries. On major road and rail crossings the method of laying the pipe is to bore a horizontal tunnel under the obstruction and line this with a pipe of larger diameter than the sleeve; the sleeved pipe is laid inside this and there is thus an additional protective layer at such points. Similar sleeving precautions are taken when the line has to pass close to buildings or where future civil or construction work is expected, and pipe of increased wall thickness may also be used (this reduces the stress in the wall). In addition at river crossings, twin underwater pipelines are used for all major rivers, with facilities for dual or separate operation.

iii. *Route selection and wayleave negotiation*

Obviously the ideal route for a pipeline is to pass in a straight line from A to B. This is rarely possible, as a route must be selected which avoids built up areas and areas scheduled for future development, and which caters for the preservation of amenities. The wayleave agreements all allow for a permanent easement of 20 ft in which no building or construction work is permitted and additionally 10 ft support strips on either side in which work can only be carried out with the permission of the Gas Council. Negotiations are understood to be in hand to increase the width of these easements with the object of providing even greater security.

iv. *Isolating valves*

In order to protect the system if accidental damage should occur, isolating valves with valved by-pass and emergency blow-down facilities are provided at regular intervals. These are at about ten-mile intervals in the open country and closer when approaching developed areas.

v. *Pig traps*

So that the line may be cleaned periodically, facilities for passing pigs (dumbbell shaped cleaning devices) are incorporated in all lines at about 30 mile intervals.

vi. Above ground installations

These consist of terminals, pigging stations, junction stations, booster stations and offtakes. Often one installation may serve more than one purpose. These stations are all provided with emergency power supplies so that they can operate safely in an emergency as self contained isolated units. Whether or not the station is manned, all the equipment etc., is contained within a 6 to 7 ft high security fence, all the vulnerable equipment and instrumentation is housed in suitable buildings, and all valves and actuators are securely locked.

vii. Maintenance and inspection

Full schedules of maintenance have been prepared which should suffice to keep the pipelines in first-class condition. Inspection of the pipelines is carried out both from the air and on the ground. Aerial inspection is particularly valuable since it should give early warning of any un-notified civil engineering work in the vicinity of the pipeline or any impending encroachment on the easement strip. The time between such inspections is normally two weeks. Additional inspections are carried out every 6 months at crossing points and at above-ground installations.

APPENDIX 4(b)

High, medium and low pressure distribution systems

4. The high pressure bulk transmission system described delivers gas to each of the Boards at pressures up to 1000 p.s.i. The Boards take the gas from the offtake points and are responsible for distributing it to the consumer. The system used may vary a little from Board to Board but in general it will consist of several networks operating at different pressures. These networks are connected together and at each stepdown in pressure the lower pressure system is protected by governors. The system to be described has, of course, developed over the last 170 years and the present arrangement may not be the same in all details as would be used in a completely new distribution system.

High pressure distribution

During the 1960s, with the advent of oil reforming as a common means of manufacturing town gas, a network of pipelines grew up to distribute this gas at pressures of up to 300 p.s.i. This network, which also uses welded steel pipes laid to high standards, has become a familiar part of the accepted gas system and has been extended and adapted for use with natural gas at the same pressure (up to 300 p.s.i.). The change of gas should not affect the safety of such systems ; the significant change is that the effective capacity of the line is doubled, due to the higher calorific value of the gas.

Medium pressure distribution

Even in the 1930s it was realized that considerable economic advantage could be gained by closing down some of the smaller manufacturing units and supplying the gas from larger central gas works, and by the middle 1950s there had developed a system of *integration mains* which when combined with *feeder mains* (which had been used to supply gas at a higher pressure (30 p.s.i.) from the gas works to remote parts of a district) were used to link areas together in a grid system carrying gas at pressures of up to 50 p.s.i. The effect of this grid, which, of course, preceded the modern pressure grid, was to enable many small gas works to be closed and converted into gasholder stations to cope with daily variation in demand. The introduction of natural gas, at the same pressure, into this system introduces similar considerations as with the high pressure system. This grid was mostly constructed of ductile iron, although steel was used in some areas.

Low pressure system

The earliest, and hence the oldest part, of the distribution system is that used to convey the gas either direct from the gas works or holder stations, or from points on the grid system, as described, to the consumers' premises. This

consists of a trunk main feeding smaller secondary mains, which in turn feed still smaller street mains. Town gas was supplied to the trunk main at pressures of up to 8 in w.g., although in some cases, in order to feed remote areas, pressures of up to 20 in w.g. were used. (This was often accompanied by the addition of simple governors on the inlet to the consumers' meter.) These mains were normally made of cast iron with some form of mechanical joint often of the open-socket lead/yarn type. This type of joint is still very common on the older low pressure mains even today, although several types of flexible mechanical joints have been introduced during the last 40 years as has the use of spun iron in place of the older vertically cast iron pipe.

With the advent of natural gas, and the need for higher burner pressures, the pressure in this low pressure system has been raised to a maximum of 20 in w.g. As already mentioned some mains have always operated at this pressure, but for most of the system this involves a substantial increase in pressure and hence has introduced a somewhat greater possibility of leakage. At the same time the introduction of a pressure governor on the inlet of every consumer's meter has accompanied this increase in pressure.

General distribution system

Thus each Area Board possesses a distribution network which is a combination of these elements, and each consumer will, on completion of conversion, be connected through a series of networks directly with the terminals at which the natural gas comes ashore. This has led some members of the public to fear that it might be possible to obtain gas at 1000 p.s.i. on their premises. This is *not* possible since at every stepdown in pressure—i.e. at every change from one system to another there is fitted a governor which will only allow gas at the correct pressure to pass. At all the main pressure change points in the system these governors are very sophisticated and are well protected against failure. The final governor, on the consumer's meter, is designed to give a constant pressure of about 8 in w.g. in the consumer's internal pipework or carcassing, a reduction from the supply pressure of 20 in w.g. These governors are subjected to rigid and exacting requirements and are tested to 40 in w.g. and under all normal circumstances should be considered safe. Concern has been expressed about their performance under abnormal pressure surges which might occur due to faults etc. in other governors further up the transmission system. Such a pressure surge did occur during the course of this inquiry in a town gas district in the Eastern Board's area, and despite contrary reports in the press, the facts are that in all cases the governors acted as required and protected the premises to which they were fitted. The only incidents which did occur were on the few premises where such governors had not been fitted. Such an occurrence was unfortunate, but should serve to quieten fears about such happenings on conversion to natural gas.

High-pressure storage

Because of the variation in demand for gas both seasonally and during the day, all systems need to have associated with them a certain amount of storage capacity. The high-pressure bulk transmission and distribution systems provide considerable scope for ' line-packing ' storage, i.e. the high-pressure mains are filled with gas up to their maximum working pressures during off-peak periods, and during periods of high demand some of this gas is made available by allowing the pressure to fall. In addition some Area Boards have installed batteries of high-pressure ' bullets ' or pipes for storage purposes. In a few cases additional storage capacity has been built into Area Boards' distribution systems by laying over-size high-pressure mains to similar sizes and pressures as the Gas Council's transmission mains, and to the same safety specification.

APPENDIX 5

Area board statistics on gas escapes in converted and non-converted areas

1. It was of interest for the purposes of this inquiry to establish, if possible, whether there were any significant differences between the numbers and locations of gas escapes in areas using town gas and natural gas. The Gas Council accordingly arranged for a survey of all escapes reported over a period of seven days (10th-17th May 1970) to be carried out by each of five Area Gas Boards, in comparable town gas (TG) and natural gas (NG) areas. A questionnaire was completed by emergency fitters of the Board's customer service departments on every reported escape during the period of the survey.

2. In selecting ' comparable areas ', the factors taken into account were

(a) the number of domestic consumers in the area, the minimum considered adequate being approximately 5000 ;

(b) the establishment (number, type and diversity) of appliances in the area ;

(c) the age of the dwellings in the area.

The areas actually surveyed were:

Area Board	*Area surveyed*	*Natural gas or town gas*	*Number of consumers*
North Eastern	Bridlington	Natural gas	10 480
	Keighley	Town gas	12 020
West Midlands	Kenilworth	Natural gas	4 800
	Hereford	Town gas	12 680
North Thames	Billericay	Natural gas	7 483
	Chiswick	Town gas	10 968
Eastern	Norfolk	Natural gas	5 188
	Felixstowe	Town gas	6 540
Southern	Leighton	Natural gas	4 916
	Newbury	Town gas	5 540

3. During the survey week there were 93 genuine escapes in the five NG areas compared with 124 in the TG areas. The average size of the TG areas was larger, however, and the number of escapes per ten thousand consumers was 28 in the NG areas and 26 in the TG areas.

Table 1 shows the number of escapes per 10 000 domestic consumers for each of the five Boards ; Table 2 indicates the relative frequency of occurrence

of these escapes from different parts of consumers' systems and different types of appliances, in terms of percentages of the total for all five Boards.

TABLE 1

Number of escapes per 10 000 domestic consumers

Gas Board	Natural gas area	Town gas area
North Eastern	12·4	20·8
West Midlands	33·3	15·0
North Thames	49·5	47·5
Eastern	27·0	30·7
Southern	26·5	14·5
Overall (all 5 Boards)	28·3	26·0

TABLE 2

Number of escapes classified according to location in consumer's system

Location of escape	Percentage of escapes (*Figures do not total* 100%, *owing to rounding*)	
	Natural gas	Town gas
Service pipe	2	3
Main cock	8	6
Meter	11	33
Internal installation pipes (carcassing)	12	9
Cooker	21	24
Room heater (gas fire)	6	11
Water heater	3	6
Refrigerator	5	0
Central heating appliance	11	2
Multiple	14	4
Other	6	1

The overall frequency of escapes, for all the territory covered by the survey, is clearly not significantly different in natural gas and town gas areas ; but in view of the testing of tightness of systems and subsequent renewal and replacement of appliance connections which precedes conversion to natural gas, the number in natural gas areas might be expected to be the lower, unless either the higher supply pressure of natural gas has caused some fresh leaks to develop after conversion, or a certain number of defective connections

have been made in the course of conversion and not detected in the call-back period following it. The number of cases under any particular heading is too small to justify any firm conclusion but Table II suggests some possible basis for further investigation. It might be worth examining, for instance, whether there is any feature in the design of central heating installations or refrigerators which makes them particularly likely to develop leaks after conversion, and whether any improvements in jointing materials used in carcassing are desirable to enable them to withstand continued pressures of about 9 inches water gauge.

APPENDIX 6

Statistics provided by the Fire Research Station

1. Local authority fire brigades each year attend a number of explosions attributed to gas escapes and report details of them to the Joint Fire Research Organization of the Ministry of Technology and the Fire Offices' Committee.

2. The Fire Research Station has examined all such reports received for 1969 in which an explosion of mains gas in a dwelling was involved. The fire authority was asked to ascertain in each case whether the gas was natural gas or town gas and to make an estimate of material damage. The results of the examination are given in the tables below. For the purposes of comparison it should be mentioned that over the year 1969 about 6 per cent. of all gas sold to domestic consumers was natural gas.

TABLE 1

Town and natural gas explosions in dwellings, Great Britain 1969

	Town gas	Natural gas	Total
England	131	17	148
Wales and Monmouthshire	2	1	3
Scotland	5	—	5
	138	18	156

TABLE 2

Material damage and injuries resulting from gas explosions in dwellings in Great Britain 1969

Town gas	Number of injuries					Total explosions	Total injuries
	0	1	2	3	4		
Material damage (£)							
0	4	8	1	—	—	13	10
1–30	30	7	2	—	—	39	11
31–100	24	9	—	—	—	33	9
101–300	17	9	—	—	—	26	9
301–1000	9	3	—	—	—	12	3
1001–3000	5	5	—	—	—	10	5
3001–10000	3	—	1	—	—	4	2
10001–	—	—	—	—	1	1	4
Total explosions	92	41	4	—	1	138	—
Total injuries	—	41	8	—	4	—	53

TABLE 3

Material damage and injuries resulting from gas explosions in dwellings in Great Britain 1969

Natural gas	Number of injuries 0	1	2	3	4	Total explosions	Total injuries
Material damage (£)							
0	1	2	—	—	—	3	2
1–30	5	—	—	—	—	5	—
31–100	2	—	—	—	—	2	—
101–300	3	—	—	—	1	4	4
301–1000	1	1	—	—	—	2	1
1001–3000	—	—	—	—	—	—	—
3001–10000	2	—	—	—	—	2	—
10001–	—	—	—	—	—	—	—
Total explosions	14	3	—	—	1	18	—
Total injuries	—	3	—	—	4	—	7

APPENDIX 7

Toxic hazards of carbon monoxide*

1. Carbon monoxide is a colourless and odourless gas, and its presence in the air of a room is undetectable by the occupants. It is extremely poisonous when breathed, as it combines with the hæmoglobin of the blood and thus diminishes its oxygen-carrying capacity. In sufficient concentration it will cause unconsciousness and death.

2. The combination of carbon monoxide with hæmoglobin produces the compound carboxyhæmoglobin, by a reversible chemical reaction to which the law of mass action applies. Hence for any given concentration of carbon monoxide in the atmosphere the amount of carboxyhæmoglobin in the blood approaches a level corresponding to a state of equilibrium, at a speed which depends on a number of factors including, in particular, the amount of physical exercise which is being undertaken. When exposure to the polluted atmosphere ceases the blood level of carboxyhæmoglobin gradually returns to normal, at a rate which also depends on the physical activity of the person concerned. Under these conditions recovery is usually rapid if the subject is rescued while still alive, but he remains liable to collapse on exertion until the carbon monoxide level in the blood has returned to a low level. Artificial respiration and inhalation of oxygen and carbon dioxide hasten recovery.

3. The following table gives the clinical signs and symptoms associated with various percentage degrees of saturation of hæmoglobin with carbon monoxide.

0—10 per cent. ...	No symptoms.
10—20 per cent. ...	Tightness across the forehead, possibly headache, flushed skin, yawning.
20—30 per cent. ...	Headache, dizziness, palpitation on exertion.
30—40 per cent. ...	Severe headache, weakness, dizziness, nausea, possibly collapse.
40—50 per cent. ...	As above with increased respiration and pulse, with more possibility of collapse and syncope.
50—60 per cent. ...	Syncope, coma, Cheyne-Stokes respiration.
60—70 per cent. ...	Coma, weakened heart and respiration, possible death.
70—80 per cent. ...	Respiratory failure and death.
90 per cent. ...	Prompt cardiac arrest.

The limit of safety is 18–20 per cent.

* Based on information provided by the Department of Health and Social Security and the Medical Research Council's Air Pollution Research Unit.

The effect of carbon monoxide uptake by the blood is dependent on a number of factors, the most important from the point of view of hazards from inadequate flueing and ventilation of combustion appliances being:

- Degree of activity.
- Previous exposure to carbon monoxide.
- Concentration of carbon monoxide inhaled.
- Presence of carbon dioxide in the atmosphere (which increases the depth of breathing).
- Diminished oxygen content of the atmosphere.
- Some physical conditions such as circulatory or blood disorders and possibly effects of alcohol or drugs. The very young and the very old are liable to be particularly affected.

Prolonged exposure during sleep can give rise to more serious neurological damage than exposure to higher concentrations under waking conditions.

4. The percentage carboxyhæmoglobin saturation reached can be roughly assessed in terms of the time of exposure if the percentage of carbon monoxide in the atmosphere, the initial concentration in the blood and the level of activity of the patient are known, by means of a nomogram published by Forbes, Sargent and Roughton in the *American Journal of Physiology,* 1945 (Vol. 143, p. 594). As examples, an 80 minute exposure to an atmosphere containing 0·02 per cent. of carbon monoxide will produce an increase in saturation of about 5 per cent. in the case of a person at rest and an increase of about 10 per cent. if the person is doing light work; if the period of exposure is 200 minutes the increases reached are 10 per cent. and nearly 20 per cent. respectively. With 0·1 per cent. of carbon monoxide in the atmosphere the carboxyhæmoglobin saturation of the blood of the person at rest will increase by about 25 per cent. in 80 minutes and by about 40 per cent. in 200 minutes, while that of a person doing light work could reach a level at which he might be unable to continue working in something like 20 minutes. The nomogram would not be appropriate for use where there is an initial high level of carboxyhæmoglobin in the blood.

5. Carbon monoxide is well-known as a highly toxic constituent of petrol vehicle exhaust gases, and a number of manufactured fuel gases including coal gas, water gas, producer gas and blast furnace gas.

6. The dangers of carbon monoxide poisoning through incomplete combustion have been well known for many years. Deaths and illness resulting from gases produced by defective coke stoves were described as early as 1891, and a number of studies of the formation of carbon monoxide in both town gas and natural gas appliances have been made in various countries (e.g. US Bureau of Mines Tech. Paper No. 337 (1923); Masterman, Dunning and Densham, Inst. Gas Engineers Publication No. 41 (1931)). Thurston in an article in the *Medico-Legal Journal* (1968, **36,** 191) has reviewed a number

of cases where death has occurred as a result of defective boiler flues. A very full account of all aspects of carbon monoxide poisoning, including statistics, clinical and pathological studies and details of the effects of poor ventilation and flueing with special reference to bathrooms, was published as a monograph by C. K. Drinker in 1938 (' Carbon Monoxide Asphyxia ', Oxford University Press (Medical Publications), New York, 1938 ; pp. 221 + bibliography). This author draws particular attention (p. 63) to the dangerously insidious character of carbon monoxide poisoning, which so impairs the mental faculties at an early stage that ' the person affected may be brought to the very verge of unconsciousness without appreciating in the least degree that anything is wrong '. This is doubtless an important factor in the very high fatality rate in carbon monoxide poisoning incidents. Another factor of particular significance in such cases as inhalation of products of incomplete combustion of gas in inadequately ventilated bathrooms and the like, is that at a stage when the subject is still conscious while at rest, even slight exertion can lead to collapse and unconsciousness, so that he is unable to extricate himself from the situation by his own efforts.

Neurological and neuropsychiatric sequelæ in severe cases of carbon monoxide poisoning have been described by Garland and Pearce (*Quarterly Journal of Medicine*, 1967, **36,** 445) and Smith and Branden (*Postgraduate Medical Journal*, 1970, **46,** 65).

APPENDIX 8

Regulations and Codes of Practice relating to the installation and flueing of gas appliances and the supply of combustion air

Building Regulations

1. The Building Regulations, 1965* derive from Section 4 of the Public Health Act, 1961, and replace former Building byelaws. The Regulations are legally enforceable and the duty of enforcement rests on Local Authorities.

2. Section A.9 requires any person who intends to install a domestic gas appliance to give notice and submit plans, specifications, etc., to the Local Authority's Building Inspector, unless such appliance is installed by or under the supervision of an Area Gas Board and no structural work is involved.

3. Section L requires that:

i. chimneys and flue pipes shall be so constructed as to prevent products of combustion escaping into the building (L.2);

ii. flues of gas appliances shall comply with certain specifications as to length, materials, cross-section, outlet terminals and use for more than one room.

4. Section M requires that any high-rating gas appliance† shall discharge into a flue and shall have provision for the supply of sufficient combustion air to ensure its efficient operation and discharge of combustion products through the flue (M.3), but permits installation of:

i. a gas cooker venting into a room;

ii. a flueless water heater if its input rating does not exceed a specified figure (e.g. 40 000 Btu/hour for an instantaneous water heater);

iii. a flueless gas fire if its input rating does not exceed 500 Btu/hour per 100 cu ft of room space ;

provided in the case of *ii* and *iii* that the room has an openable window and a permanent vent of a specified unobstructed cross-section, and that bath water heaters must be room-sealed unless the capacity of the room exceeds 200 cu ft and the input rating does not exceed 500 Btu/hour per 100 cu ft of room space.

---

* Including First and Fifth Amendments made over the period 1965–70. These Regulations apply to England and Wales (excluding the former L.C.C. area, to which separate Regulations apply). Separate Regulations similar to those for England and Wales apply in Scotland.

† i.e. appliances with an input rating exceeding 150 000 Btu/hour. Nearly all domestic gas appliances are smaller than this.

British Standards Codes of Practice

5. Codes of Practice CP 332–335 comprise recommendations for the installation of gas appliances and for flues and ventilation. These Codes are more detailed than the Building Regulations but are not equally up to date and are not legally binding. In principle, they provide a potential basis for 'deemed to satisfy' provisions of the Building Regulations.

Gas Council standards for ventilation of gas appliances

6. These were issued by the Gas Council's Service Committee in 1968 and are an extension of the standards of existing regulations and codes of practice. They are in a form suitable for use by survey teams and installers, and cover modern 'combined' appliances and the use of natural gas.

London Gas Undertakings Regulations

7. Within those parts of the former London County Council area which are served by the North Thames and South Eastern Gas Boards, these Boards have a duty to ensure that all installation of gas appliances and associated flueing and ventilation shall be carried out in accordance with standards set out in the London Gas Undertakings Regulations, 1954.* These standards are legally binding on the two Gas Boards, contractors employed by them, and others. To ensure that all work covered by the Regulations is executed in compliance with them, the Gas Boards have powers of entry to premises and inspection of installations, and must be notified of intention to execute such work.

Recent proposals

8. New regulations have been proposed under Section 67 of the Gas Act, 1948 (see Appendix 1), but not yet laid before Parliament. They include requirements for appliances to conform with certain British Standard specifications or to be acceptable to Area Gas Boards, and for all associated pipes, fittings, flues and ventilation to be consistent with safety in use. They also prescribe tests for soundness, correct adjustment and satisfactory operation of flues, and provision of combustion air.

9. Recently proposed national legislation to enable Gas Boards to enter premises for inspection of installations and disconnect gas supplies to potentially dangerous equipment is referred to in Appendix 1.

* Revised Regulations have been prepared and are awaiting the approval of the Minister of Technology.

APPENDIX 9

Conversion procedures

1. Conversion of gas appliances to burn natural gas is a continuing process for Gas Boards. No new plant for producing town gas is being constructed and Boards have therefore to arrange that natural gas is introduced at a rate that will ensure that, as demand for gas continues to rise, the existing town gas plant remains adequate to serve the gradually diminishing town gas areas.

2. The general programme of conversion has been decided in advance by Gas Boards after computer studies which took into account availability of natural gas, capacity of mains and gas plant and other relevant factors. A general outline of the progress of conversion each year and a forecast for the following year are given in the Gas Council's Annual Reports.

3. The sequence of operations in effecting conversion is essentially the same in all Gas Boards' areas, and is as follows:

i. Some 75 weeks before conversion is due in any particular part of a Board's area, individual conversion sectors are finally agreed between the Conversion and Distribution Departments of the Board, the boundaries of the sectors are precisely defined and it is ascertained by means of a survey that the distribution system in the sector is in a satisfactory condition for the supply of natural gas to consumers. The local distribution department ensures that the sector boundaries are practicable and that it is feasible to install valves to isolate the sector.

ii. About one year before conversion a survey of industrial consumers is carried out so that procedure on conversion can be agreed with them, thus minimising dislocation of their operations. By the use of spur mains and with the agreement of the undertakings concerned, it is sometimes possible to convert larger industrial plant well in advance of surrounding sectors.

iii. At around the same time the Board's Distribution Department issue their proposed sector plans to Local Authorities and consumers' representative associations. The size of each sector represents the number of consumers which the Conversion Department can conveniently convert in a single operation taking into account the time of year, the type of conversion cycle, the size of the labour force available, and the appliance density, allowing for holiday periods where appropriate.

iv. About 38 weeks before the date fixed for conversion, consumers are informed that the Board's fitters will visit their premises to install a service governor to regulate the supply of natural gas to their premises at the appropriate pressure, which is higher than that used for town gas. When the service governor is installed (about 36 weeks before

conversion) the Board's fitters carry out a test of the soundness of the internal installation pipework (carcassing) of the premises to ensure that it does not leak at this increased pressure. The test is made at a pressure higher than the pressure at which natural gas will be supplied.

v. Some 18 weeks before conversion, domestic consumers are informed that a Board representative will call to conduct a survey of their gas appliances. The primary purpose of the survey, which commences two weeks later, is to provide the conversion department with an inventory of appliances to be covered so that the provision of conversion kits can be organized in advance. In the course of it the surveyors carry out safety checks on flued instantaneous water heaters in bathrooms, flueless space heaters and central heating and warm-air equipment. The surveyor is provided with a standard form for reporting any appliance and associated ventilation and flueing systems which appear to be faulty. The results of the survey are fed into a computer and so far as is possible the records are kept up to date from that time until conversion takes place.

4. About 13 weeks before the conversion date, consumers receive a letter from the Board inviting them to purchase a new appliance from the Board at a reduced price rather than having the existing appliances converted. In the case of older appliances which are difficult to convert, the Board may offer to replace them with reconditioned equivalents. Attention is drawn to the existence of any potentially dangerous flueing or ventilation conditions and the consumer is urged to rectify these faults. It is the householder's own responsibility to ensure at his own expense that such systems are safe, but Area Boards can usually arrange to carry out the work involved, often at a nominal charge.

5. Two weeks before conversion each consumer receives precise details of the day on which conversion will start, the sequence of operations involved and of how he can assist. The kits which will be used to convert appliances are usually delivered to consumers' homes during this period. A further letter is sent one week before conversion date asking consumers to ensure that the Board's representatives can gain access to their premises early on the conversion date. Consumers are warned that if access cannot be obtained it may be necessary to disconnect the gas service pipe outside the house.

6. The length of the actual conversions operation, as it affects the consumer, depends on whether a two-day or a five-day cycle is adopted. The five-day cycle operates on larger sectors, and the arrangements for it are as follows:

Monday

i. 8.0 a.m.-9.0 a.m. ' Make safe ', i.e. the conversion teams visit all premises, turn off all meter and appliance control cocks, and disconnect the gas supply in cases where they are not able to get into premises.

ii. 9.0 a.m.-10.15 a.m. 'Turn in'. In this operation the town gas valves in the sector are closed and the natural gas valves are opened. The town gas remaining in the mains is purged through stand-pipes erected at convenient points in the sector.

iii. 10.15 a.m.-11.30 a.m. Meter cocks are opened to introduce natural gas and the consumer is given a demonstration of hotplate cooking by using the taps in the 'half-on' position (known as 'turn-down'). Other appliances are labelled *'Do not use'*, as are the grill and oven on cookers. If by reason of old age, language difficulty or other causes consumers seem not to understand the 'turn-down' procedure converters ask them not to use the cooker and it is treated as a priority appliance and converted later in the day. Special priority treatment is arranged for incapacitated consumers.

iv. 11.30 a.m. onwards. The delivery of any further materials required for conversion is completed and priority appliances, e.g. space heating in winter, water heaters and refrigerators in summer, are converted.

Tuesday

Conversion of priority appliances is completed and a start made on cookers.

Wednesday

Conversion of cookers is completed.

Thursday and Friday

Non-priority appliances, e.g. fires in bedrooms, coke grate igniters, wash boilers, are converted.

7. All the activities in a sector undergoing conversion are controlled from a mobile base, radio contact being available between the base and all vehicles engaged in the operation.

8. A special telephone control centre is set up through which any difficulties can be reported; details of these arrangements are given to consumers within conversion sectors and calls received are referred for the attention of the conversion contractor, who is responsible for dealing with consumer complaints arising out of conversion for a period of several weeks. After that time correction of faults attributed to conversion will be dealt with free of charge by the Board for an indefinite period.

9. Consumers are also supplied with pre-paid cards with which complaints may be notified. The Boards employ Home Service Advisers, who are available before conversion to give demonstrations of the use of natural gas and also visit any consumers who appear to have difficulty in becoming accustomed to using natural gas following conversion.

10. The procedure outlined above is varied in detail by individual area Gas Boards. When a two-day cycle of conversion procedure is adopted, the sectors are smaller, and instead of the 'turn-down' technique on cooker hotplates, hotplate burners are dealt with during the morning of the conversion date between the 'make safe' and the 'turn-in' stages of the cycle, while other appliances are either sealed off and converted in advance the previous day or converted in the afternoon of the conversion day. Two two-day cycles are carried out in each week, one sector being converted on Monday and Tuesday and a second on Wednesday and Thursday. Friday is reserved for dealing with queries and difficulties which have arisen during these two cycles.

Statistics of conversion

11. The conversion operation for the whole of Great Britain involves 13 million domestic, 550 000 commercial and 80 000 industrial consumers. The domestic consumers have 30½ million appliances and the commercial and industrial consumers have another 10 million. The number of distinct domestic appliance models which have been identified is 6197, of which 959 are current models, 2635 non-current (i.e. no longer on the market but with replacement parts still obtainable) and 2603 obsolete (i.e. neither the appliance nor any component of it can still be purchased). The total of 6197 models includes 1573 cookers, 1823 gas fires, 1724 central heating appliances and 516 water heaters.

12. Among the 13 million domestic consumers there are:

10·95 million cookers (84 per 100 consumers).

6·8 million gas fires (52½ per 100 consumers).

1·94 million central heating appliances (15 per 100 consumers).

2·89 million water heaters (22½ per 100 consumers).

2·28 million wash boilers and other laundering appliances (17½ per 100 consumers).

'Sell-out' and 'ad hoc' procedures

13. The cost of conversion of old appliances is high and there is no general provision of spare parts by manufacturers for appliances over 15 years old. All Area Gas Boards therefore offer special terms to customers for the purchase of new appliances before conversion to replace old ones. This is to the advantage of the Board as well as the customer, as a difficult conversion problem is eliminated if the customer accepts the offer.

14. Where, for any reason, the customer wishes to retain an obsolete appliance for which there is no standardized conversion set, the appliance is removed to a special conversion workshop during the conversion period and such alterations are made to it as will enable it to function effectively on natural gas. This may involve a wide variety of modifications, such as drilling out burner ports, fitting new injectors, altering the position and number of burners, and providing additional combustion chamber space. Sometimes the original construction cannot be modified sufficiently to enable the appliance to be used at its original heat output, and it must be 'down-rated' to operate on a reduced output on natural gas. In such cases any attempts to restore the original output by increasing the gas supply involve a risk of 'overgassing' and incomplete combustion and are potentially dangerous.

APPENDIX 10

Approval procedures for appliances and conversion sets

General

1. The Gas Council maintains an establishment known as Watson House which has a technical division dealing with approval and installation work.

2. The approval scheme operated by the Gas Council covers:

Domestic gas appliances.

Gas catering appliances.

Commercial gas appliances (for heating purposes).

Controls for domestic, catering and commercial appliances (including pumps).

Flexible flues and terminals.

Brass fittings.

Tests are carried out, to British Standards where appropriate, to ensure that all the items appearing on the Gas Council's lists of tested and approved equipment are of an acceptable standard, or better. Gas Boards are kept informed of the results of tests when any item is approved, and they will not sell anything which has not been approved.

British Standards and Gas Council agreements with appliance makers

3. The three basic British Standards for appliances are:

BS 1250. 'Domestic Appliances Burning Town Gas' (latest parts 1963–66).

BS 2512. 'Gas Heated Catering Equipment' (1963).

BS 3561. 'Non-domestic Space Heaters Burning Town Gas' (1962).

4. If a new need is evident the Gas Council negotiates an agreement with manufacturers' associations. The contacts are most frequent with the Society of British Gas Industries, which represents over 200 firms, but where appropriate, the Catering Equipment Manufacturers' Association and the National Association of Restaurant Engineers are also involved.

Test gases

5. The most basic test provisions refer to the gases to be used for tests. Manufactured gases are grouped according to Wobbe number. BS 1250 Part 1 defines five test gases for each of three gas groups; in practice most tests are carried out using gases for the middle group, G4, which corresponds to the greatest usage in the UK. Agreements have been made as to the nature of test gases for natural gas.

6. If gas could be distributed having constant composition and therefore constant burning properties, approval testing of appliances would consist of ensuring satisfactory performance of this gas. Any variation in performance on the district would arise from the inevitable tolerances in appliance manufacture, or from the deterioration of the appliance in use. Such variations are covered in approval testing by tests at under-load and over-load, in which the heat input is altered to allow for variations in injector size, aeration, and conditions of use.

7. In general, however, it is not possible to distribute a constant gas. The main requirements for satisfactory appliance performance are that, despite some variations in gas composition, the heat input should remain reasonably constant, the flames should be stable, there should not be significant formation of carbon monoxide or soot and ignition should be satisfactory. Given the mean and extreme values of the combustion characteristics, the gas appliances can be tested to ensure that they will give optimum performance on the average gas and safe and tolerable performance on gases of extreme characteristics. For this purpose, several test gases are used, each one being required to assess a particular kind of possible malfunctioning, i.e. incomplete combustion, light-back, lift and sooting. One set of test gases has been established by Watson House for town gas appliances, and another set for natural gas appliances.

Tests for safety

8. The basic safety test carried out on all appliances determines the completeness of combustion. A gas of high Wobbe number is used for one test, but the most searching test is usually conducted at 120 per cent. of the normal heat input. With the appliance operating at an ' overload ' heat input, samples of flue gas are taken and analysed for the oxides of carbon they contain. The worse the combustion, the more carbon monoxide is produced. Hence, the ratio of carbon monoxide to carbon dioxide is a measure of completeness of combustion. Under overload conditions, this ratio must not exceed 0·02. Tests are also made under adverse flueing conditions, particularly down draught in conventional flues.

9. Other tests for safety include those for limiting surface temperatures, fire hazards, and gas tightness. Because natural gas has to be used at higher pressures than manufactured gas to give equivalent results, soundness checks are carried out at 16 in w.g. on natural gas, as opposed to 12 in w.g. on manufactured gas. Attention is also paid to marking or positioning of cocks and taps to avoid inadvertent operation.

10. In some cases it is important to test appliances which may operate in confined spaces without a flue. This is done by placing them in an airtight room and allowing them to burn. Oxygen is consumed and carbon dioxide

is produced. The amount of carbon dioxide is a measure of oxygen depletion. The Standards demand that flueless appliances shall still operate when there is so much carbon dioxide in the room atmosphere that the consumer would feel so uncomfortable that he would have taken action to increase ventilation. A level of 1·5 per cent. carbon dioxide is prescribed for natural gas burning appliances (2 per cent. for manufactured gas). Even so, with this level of oxygen depletion, the CO/CO_2 ratio of 0.02 must not be exceeded.

11. Some appliances, such as instantaneous water heaters, are required by the Standards to undergo a life test, following which they must continue to give satisfactory operation on manufactured gas. The low sulphur content of natural gas makes it unnecessary to carry out this test if the heater is to use no other gas.

Conversion

12. The immediate problem in conversion is to provide the correct physical bits and pieces in the form of a 'conversion set' to allow a fitter to alter an appliance to make it operate satisfactorily on natural gas. Watson House set up a special conversion laboratory devoted solely to the testing of conversion sets in October 1966. The team had dealt with 3500 sets by 1 January 1969 when the decreased work load permitted testing of sets to follow the normal approval procedure. The laboratory was staffed by people from Gas Boards as well as Watson House. Attention was concentrated on current appliances and those for which, under a Gas Council rule, spare parts were being held for a period of up to 15 years following the end of production. The onus was placed on the manufacturers of the appliances to develop conversion sets and for drafting the conversion instructions forming part of the conversion manual.

13. To test the conversion sets, old appliances had to be obtained, and each appliance was converted by the laboratory staff using standard fitters' tool kits and manufacturers' instructions.

14. The aim was always to give the consumer 'parity of performance' before and after conversion, but this target was not allowed to stand in the way of safety requirements. The 120 per cent. heat input overload test was always applied, and this sometimes meant that on conversion to natural gas, the normal heat input to the appliance had to be reduced. All conversion sets were tested using the full range of test gases.

Quality control

15. To gain permission to use the Gas Council's seal of approval, a sample appliance, certified as representative of production, is examined and tested at Watson House. If all is well, a licence to use the seal of approval may

be issued. It is clearly desirable to ensure that what is made does in fact correspond with the sample originally submitted. A team of men concerned entirely with production standards is employed, based on Watson House, to see that this is so. Reported faults, and particularly recurrent faults shown up by district experience, are also dealt with by this team.

Codes of Practice

16. If an appliance is approved, it can be expected to give safe operation provided that it is installed properly. Ventilation is vital to the proper functioning of all but room-sealed appliances.

17. Adequate ventilation is achieved if the appropriate British Standard Codes of Practice are heeded. These Codes, listed below, are prepared by drafting panels of a Committee meeting under the aegis of the Institution of Gas Engineers and reporting to the British Standards Institution. Watson House maintains a small team producing material for consideration by the drafting panels, and the resources of its Research and Development Division are available if any experimental work is needed.

Relevant BS Codes of Practice

CP 331 Installation of Pipes and Meters for Town Gas

- Part 1 (1957) Service Pipes
- Part 2 (1965) Metering and Meter Control
- Part 3 (1965) Installation Pipes

CP 332 Selection and Installation of Town Gas Space Heating

- Part 1 1961 Independent Domestic Appliances
- Part 2 1964 Central Heating Boilers for Domestic Premises
- Part 3 1970 Central Heating Boilers of more than 150 000 Btu/h and up to 2 000 000 Btu/h. (Approved by B.S.I. but awaiting publication.)

CP 333 Selection and Installation of Town Gas Hot Water Supplies

- Part 1 1964 Domestic Premises
- Part 2 1948 Schools

CP 334 Selection and Installation of Town Gas Cooking and Refrigerating Appliances

Part 1 (1962) Domestic Cooking Appliances

Part 2 (1966) Cooking Installation

Part 3 (1947) Refrigerators

CP 335 Selection and Installation of Miscellaneous Town Gas Appliances
Part 1 (1960) Laundering and Miscellaneous Domestic Appliances

CP 337 1963 Flues for Gas Appliances.

APPENDIX 11

List of persons and organisations who gave evidence to the inquiry

Members of Parliament

*Joel Barnett, Esq.
Bernard Braine, Esq.
Douglas Dodds-Parker, Esq.
*Sir John Eden, Bt.
*David Lane, Esq.
*Dudley Smith, Esq.

Professional and specialist associations

Institute of Fuel.
Institution of Gas Engineers.
Society of British Gas Industries.
Institution of Heating and Ventilating Engineers.
Confederation for the Registration of Gas Installers.
Gas Conversion Association.
Heating and Ventilating Contractors Association.
National Association of Restaurant Engineers.

Medical practitioners

*Dr. T. B. Anderson, M.R.C.S., L.R.C.P., M.D.
*Dr. D. F. Barrowcliff, B.M., B.Ch.
Dr. G. Austin Gresham, T.D., M.A., M.D.

Organizations representing interests of consumers

Consumer Council.
North Western Gas Consultative Council.
North Eastern Gas Consultative Council.
West Midlands Gas Consultative Council.
Eastern Gas Consultative Council.
North Thames Gas Consultative Council.

---

* Gave oral evidence.
† Visited in the course of the inquiry.

The British gas industry

†The Gas Council.

†Eastern Gas Board.

†North Eastern Gas Board.

†North Thames Gas Board.

†North Western Gas Board.

†West Midlands Gas Board.

Overseas gas industries

†Association Royale des Gaziers Belges.

†Electrogaz SA (the gas supply organization supplying Brussels and district).

†Vereniging van Gasfabrikanten in Nederland, Rijswijk, Netherlands.

†Gas Instituut VEG, The Hague, Netherlands.

Government departments and research organizations in the U.K.

†Gas Standards Branch, Ministry of Technology.

*Ministry of Housing and Local Government.

*Department of Health and Social Security.

*Medical Research Council.

*Fire Research Station (Ministry of Technology and Fire Offices Committee).

Safety in Mines Research Establishment (Ministry of Technology).

Organizations representing workers in the gas industry

*General and Municipal Workers Union (represented by Sir Frederick Hayday, C.B.E.).

*National and Local Government Officers Association (represented by F. C. Henfrey-Smith, Esq., S. W. E. Richards, Esq., S. G. Bishop, Esq. and R. H. T. Jones, Esq.).

Appliance manufacturers

*The Radiation Group of Companies (represented by I. H. Phillipps, Esq., M.A., C.Eng., F.I.C.E., F.I.Gas.E., R. E. Byford, Esq., C.Eng., F.I.Gas.E., and N. Barnes, Esq., C.Eng., F.I.Gas.E.).

*Thomas Potterton, Limited (represented by Leslie Coles, Esq., C.Eng., F.I.Gas.E.).

Conversion contractors

*Servotomic, Limited (represented by J. R. Davis, Esq.).

*William Press, Limited (represented by R. G. L. Morgan, Esq.).

Others

*C. J. Cooke, Esq., M.I.P.H.E., M.A.P.H.I., of the Association of Berkshire Surveyors.

*Dr. Ian Fells, M.A., Ph.D., F.R.I.C., M.Inst.F., of University of Newcastle upon Tyne.

*Dr. M. A. Phillips, D.Sc., C.Eng., F.R.I.C., M.I.Chem.E., of Phillips Associates, Consulting Chemists and Chartered Chemical Engineers.

(879673) Dd. 501201 K48 8/70 St.S.

MINISTRY OF TECHNOLOGY

Report of the Inquiry into the Safety of Natural Gas as a Fuel

by

Professor Frank Morton

O.B.E., M.Sc. Tech., Ph.D., D.Sc., C.Eng., F.R.I.C., M.I.Chem.E.

LONDON

HER MAJESTY'S STATIONERY OFFICE

1970

SBN 11 410095 0

Contents

		Page
1	**Introduction**	1
2	**General considerations**	4
3	**Natural gas and town gas**	7
4	**Hazards of explosion and fire**	10
5	**Hazards of incomplete combustion**	15
6	**Conversion of systems to natural gas**	24
7	**Industrial and commercial applications**	30
8	**Maintenance of appliances**	32
9	**Prospects for the future**	33
10	**Conclusions**	36
11	**Recommendations**	38
	Appendices	
1	The organization and structure of the Gas Industry	40
2	Statistics of accidents	44
3	Properties of town gas and natural gas	46
4	(a) High pressure bulk transmission system	60
	(b) High, medium and low pressure distribution systems	63
5	Area Board statistics on gas escapes	66
6	Statistics provided by Fire Research Station	69
7	Toxic hazards of carbon monoxide	71
8	Regulations and Codes of Practice	74
9	Conversion procedures	76
10	Approval procedures for appliances and conversion sets	81
11	List of persons and organizations who gave evidence	86